



## Zonal Water Injection Technology for Highly-deviated Wells

China National Petroleum Corporation

Water flooding is the most cost-effective proven method to maintain reservoir pressure so as to stabilize output of oilfield and enhance development efficiency. As to highly heterogeneous reservoirs with high water cut, CNPC has developed the zonal water injection technology for highly-deviated wells to further improve oil recovery by water displacement.

By far, this technology has been applied in 11 wells, with the maximum deviation angle of 55°, maximum pressure of 56MPa and maximum temperature of 135°C.

### Technical Principle and Features

CNPC's zonal water injection technology for highly-deviated wells is based on a bridge concentric structure. Concentric connection and adjustment between control instrument and regulator is adopted to ensure successful connection for highly-deviated wells. The innovative eccentric valve features low leakage and low regulation torque, making water regulating easy and convenient. Bridge channel is employed to enable direct flowrate measuring for each layer and ensure measurement accuracy in highly-deviated wells.

This technology enables on-line direct reading and measuring of multiple downhole parameters such as flowrate, tubing pressure, formation pressure and temperature for each water injected layer. Also it enables downhole flowrate dynamic adjustment automatically with no need to run and fish downhole valve. A steel cable with single core is employed for two-way data transmission. Flowrate measuring and adjusting at each layer can be done efficiently and accurately with low cost and low operational risk.

## Zonal Water Injection System

The zonal water injection system is composed of downhole regulator (including adjustable valve), downhole control instrument and surface control system. Concentric connection and adjustment between control instrument and regulator is adopted to enable real-time monitoring of layer parameters, automatic measuring and adjusting of flowrate and on-line packer seal test.



System configuration

### Downhole adjustable regulator

The regulator works downhole permanently to allocate flowrate at each layer. It is composed of locating mechanism, adjustment structure, adjustable valve and bridge channel. The valve is integrated with the regulator to eliminate the need for running and fishing.

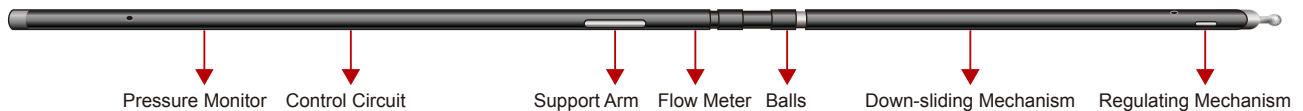
- ✓ Concentric connection and adjustment ensures high connection success rate in highly-deviated wells.
- ✓ Eccentric valve with a small size has a maximum leakage of 0.5m<sup>3</sup>/d (22MPa) when the valve is fully closed.
- ✓ Regulation torque is low and the valve is easy to regulate under the same differential pressure.
- ✓ Bridge channel is designed to eliminate inter-layer contradiction to ensure high efficiency.
- ✓ During water allocation, the valve core moves in straight line without rotation, avoiding long-term impact.



*Downhole adjustable regulator*

### Cable measuring and adjusting instrument

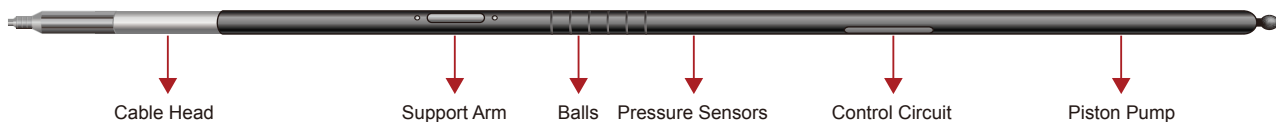
It can obtain multiple downhole parameters such as layer flowrate, tubing pressure, formation pressure and temperature in a real-time manner, and enables downhole flowrate dynamic adjustment automatically. The instrument is composed of cable head, pressure sensor, support arm, high-precision electromagnetic flowmeter, two electrically controlled balls, regulating mechanism and weight bar (optional).



*Cable measuring and adjusting instrument*

### Downhole packer seal test instrument

It is conveyed in hole via a steel cable to be concentrically connected with the regulator. The instrument can complete all packer seal test operations on line in just one trip. The instrument is composed of cable head, support arm, seal balls, pressure sensors (tubing pressure, formation pressure and ball pressure), control circuit, piston pump and weight bar (optional).



*Downhole packer seal test instrument*

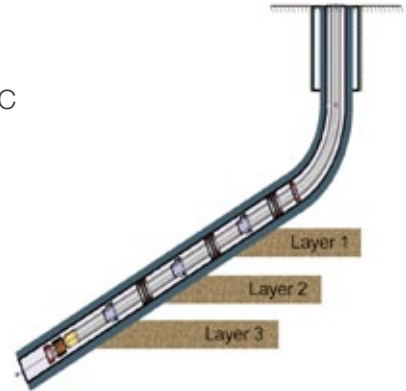


## Case Studies

### Basic information of Well NP32-X3025 in Jidong Oilfield

- Maximum deviation angle 50.7°
- Artificial hole depth 3,614m
- 3-layers/3-stages
- Formation temperature 116.71°C
- Tubing pressure 11MPa
- Casing pressure 0MPa

The downhole valves are fully open. Before the use of this technology, eccentric string was used to conduct separate layer water injection at three stages. Downhole valves were run and fished via a wireline to implement measurement and adjustment.

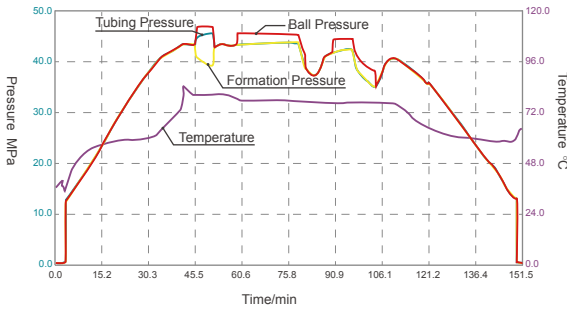


### Flowrate allocation program

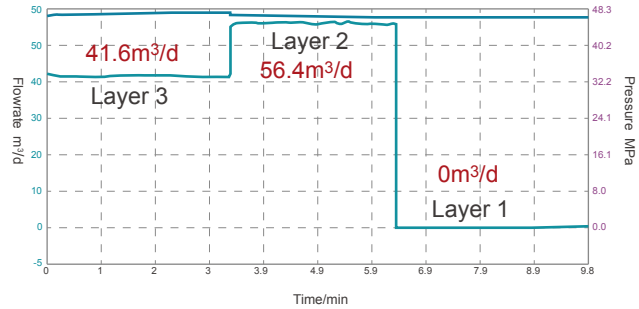
- Layer 1 3451.0-3470.0m No water injection initially
- Layer 2 3507.6-3559.4m Water injected at a rate of 50m<sup>3</sup>/d
- Layer 3 3624.0-3671.0m Water injected at a rate of 50m<sup>3</sup>/d

### Operation process

#### 1. On-line packer seal test



#### 2. On-line measuring and adjusting of layer flowrate



	Allocated flowrate (m <sup>3</sup> /d)	Flowrate measurements		
		Actually measured water flowrate (m <sup>3</sup> /d)	Surface water flowrate (m <sup>3</sup> /d)	Tubingpressure (MPa)
Full hole	100	98.0	100	13.48
Layer 1	0	0		
Layer 2	50	56.4		
Layer 3	50	41.6		

Result of NP32-X3025 on-line water allocation measuring and adjustment