PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 44, Issue 4, August 2017
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2017, 44(4): 644–651.

RESEARCH PAPER

Connotation, application and prospect of the fourth-generation separated layer water injection technology

LIU He*, PEI Xiaohan, JIA Deli, SUN Fuchao, GUO Tong

PetroChina Research Institute of Petroleum Exploration & Development, Beijing 100083, China

Abstract: The fourth-generation separated layer water injection technology was studied aiming at problems existing in current separated layer water-flooding technologies and production requirements. This paper discussed the connotation, core tool and key technologies, analyzed field application and prospected further development. The connotation is to realize digital real-time monitoring on single-well separated layer pressure and injection rate of injectors, network informationization of injection performance monitoring of blocks and reservoirs, and integrated reservoir and production engineering by combining injection program design and optimization with real-time adjustment of down hole separated layer water injection. An integrated water distributor, a core tool for this technology, and some key technologies including interval flow rate detection and injection allocation adjustment were developed. Moreover, this new technology was piloted in blocks and achieved expected results. In order to meet production requirements, it is necessary to keep research on key technologies, such as downhole interval flow rate detection, wellbore wireless communication, downhole self-power generation and vulnerable components fishing. In addition, this technology shall be properly combined with reservoir engineering, thereby developing a systematical and complete fourth-generation separated layer water injection technology that can underpin water flooding development sustainably.

Key words: water flooding development; reservoir engineering; separated layer water injection; qualification rate of water injection; cable measuring and adjusting; flow rate measuring

Introduction

Waterflooding is a predominant way to improve oilfield recovery in China. In the Daqing oilfield, the annual output has been maintained at 5 000×10^4 t for 27 years straight by waterflooding, and still 67% of the yield is from waterflooding. As for the Changqing oilfield, more than 98% of the output depends on waterflooding[1–3]. Waterflooding recovery efficiency is dependent on oil displacement efficiency and swept volume of injected water. For a specific oilfield with certain reservoir pore structure and properties of reservoir fluid and rock surface, displacement efficiency won't have much change at certain injection pore volume multiples if physical and chemical properties of injected water don't change[4–5]. Therefore, the key to enhancing waterflooding recovery efficiency is to expand swept volume of injected water, which is of particular importance for heterogeneous multilayer reservoirs.

Oilfields in China are heterogeneous in general, so great physical differences between developed layers, serious plane and interlayer contradictions, and uneven producing degree are common, and separated layer water injection is employed to stabilize production and control water cut. Its main purpose is to further tap the potential in thin poor layers and thick layers by adjusting interlayer and internal structures. Interlayer structure adjustment is mainly carried out by fine water injection and fine production of injectors and producers respectively to balance oil production of each layer. Internal structure adjustment is to subdivide injection layers by using relatively stable internal structure interfaces, thereby decreasing sublayers and perforating thickness in an interval, so different water allocations are adopted for oil layers with different permeabilities. Thus, separated layer water injection is one of important ways for enhancing oil recovery and improving development.

After over 60 years of development, separated layer water injection technologies in China have gone through three generations, from fixed injection, to steel-wire fishing, and cable measuring and adjusting water injection, and have played important roles in maintaining high and stable production and improving waterflooding recovery. However, there is still a pretty big gap from objectives established at the early development stage, especially in tackling problems such as the complicated relationship between injection and production,

Received date: 19 Aug. 2016; **Revised date:** 15 Mar. 2017.
*** Corresponding author.** E-mail: liuhe@petrochina.com.cn
Foundation item: Supported by the National High Technology Research and Development Program (863 Program), China (2012AA061300).

frequent changes of displacement performance in medium or high-permeability reservoirs of the Daqing oilfield at high water cut stage and ultralow-permeability reservoirs in Changqing oilfield at medium or high water cut stage. The contradiction between existing technologies and production demands as well as the supports for reservoir analysis data is still very serious. Therefore, the fourth generation fine layered water injection technology has been developed to transform the injection technology towards digitization, automation and integration, realizing integration of reservoir and engineering, of which the spirit is to enable real-time monitoring and automatic adjusting of layered injection parameters during whole process and realize synchronization of injecting, measuring and adjusting. In this technology, the continuous real-time data is used as the support for fine reservoir analysis, so as to enhance the pertinence and rationality of production measures, thus to achieve goals of fine water injection; the real-time and automatic adjustment of layered injection can ensure waterflooding qualification rate to realize effective water injection. Therefore, this technology is capable of expanding swept volume by means of increasing geological analysis precision and injection qualification rate, thereby improving the effect of waterflooding development.

1. History of separated layer water injection

Water channeling along high-permeability layers is likely to occur during waterflooding process, as 92% of the reservoirs in the oilfields across China are continental clastic rocks with strong vertical heterogeneity. Separated layer water injection technology was put forward and carried out in the 1960s, and so far it has experienced three generations of innovation, fixed injection, eccentric fishing, and cable measuring and adjusting. The adjustment way of water distribution has evolved from string tripping to water nozzle tripping, and to ground direct-adjusting. The data acquisition has evolved from single parameter log to multiple parameters log, and from card marking to electronic saving and ground direct-reading[6]. The pipe strings used in separated layer water injection have changed from fixed-type[7], movable-type[8], conventional eccentric-type string to concentric integrated-type[9] and bridge eccentric string[10]. The supporting techniques for measuring and adjusting have developed from steel-wire fishing to steel tube cable direct measuring and adjusting[11–14].

1.1. Fixed separated layer water injection

The fixed separated layer water injection system including 475-8 hydraulic differential pressure packer, 745-4 fixed distributor, circulation valve, test valve seat, checking seal, and layered testing was developed and applied in the early 1960s, enabling multilayer quantitative water injection for the first time. The core tool was the 475-8 hydraulic differential pressure packer, which was the designed independently for the first time in China, and marked a turning point in waterflooding development. In this technology, the flow rate measuring of layers was done by ball dropping; when adjusting injection rate, downhole string needed to be pulled out to replace distributor nozzle on the ground. This technology has been widely deployed in the Daqing oilfield.

1.2. Steel-wire fishing separated layer water injection

With the expansion of oilfield development area, water injection wells increase and water cut keeps rising consequently, which requires the injection rate could be adjusted promptly to maintain the balance of injection and production. The first-generation separated layer injection technology was unable to meet the requirements. Therefore, in the 1980s, four innovative separated layer water injection technologies characterized by steel-wire fishing measuring and adjusting were developed, namely hollow movable injection, eccentric injection, concentric-integrated subdivided injection and bridge-eccentric injection. Bridge-eccentric separated layer injection, with more advantages in the injection interval number and interlayer interference during measuring and adjusting, became the mainstream waterflooding technology in oilfields across China from the 1980s to 90s.

The string used in bridge-eccentric separated layer water injection is composed of Y341 washable packer, bridge-eccentric distributor with 46 mm inner diameter, blanking plug, and one-way valve, etc. In this technology, fishing or pressure and flow measurement of the target layer are done by steel-wire without affecting other injection layers. The steel-wire fishing separated layer injection, represented by bridge-eccentric injection, was the most adaptable, mature and widely used technology at that time, and it is still employed in some oilfields of China.

1.3. Cable measuring and adjusting separated layer injection technology

With the ongoing of oilfield development, interlayer contradictions were sharpening. Therefore, the measuring and adjusting period needed to be shortened to ensure injection qualification rate, which brought about new requirements to the measuring and adjusting operation of separated layer injection. In order to reduce field test time and workload, a separated layer injection technology with the cores of "bridge-eccentric or -concentric and cable measuring and adjusting" was developed and applied in the 1990s. The core of this technology is that downhole electric measuring and adjusting instrument, carried into the well by steel tube cable instead of steel wire, utilizes integrated sensors to collect flow rate, pressure, temperature and other signals online when reaching the specified layer; and the adjusting arm of the instrument could dock with blanking plug of bridge-eccentric distributor to adjust injection rate by electric driving and transmission mechanism. This technology has significantly improved the measuring and adjusting efficiency of injectors, and has become the mainstream technology of separated layer injection in China.