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ENGINEERING MANAGEMENT THEORIES AND METHODOLOGIES

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Persistent Integration and Innovation Management Mode and Its Applications in Petroleum Production Engineering

Abstract This paper proposes a new management mode named the persistent integration and innovation management mode to satisfy the requirements by the fast development at oilfields. Taking engineering philosophy as the guidance and technical innovations in petroleum production engineering as the breaking point, the management mode combines long term production practice at oilfields with modern management methods. The management mode integrates intellectuals, techniques, capital, and information and so on to accomplish global optimization of resource configuration. Sets of new techniques, new methods, new technologies and new equipment in petroleum production engineering have been proposed under the guidance of the management mode, achieving great social and economic benefits.

Keywords: integration and innovation, engineering philosophy, petroleum production engineering, Daqing Oilfield

1 Introduction

Petroleum production engineering is the collection of a variety of techniques that are used in reservoirs via production and injection wells. These techniques are utilized according to development plans during petroleum production at oilfields. Petroleum production engineering is a bridge that connects resource underground with infrastructure on the ground and plays a critical role for effective reservoir development. Petroleum production is a complicated and multi-disciplinary system engineering that covers separated layer water-flooding, stimulation, artificial lifting, reservoir chemistry, and downhole servicing operation, and so on (Liu, 2008). Due to historical challenges nowadays in the petroleum industry, it is necessary to find a management mode that can always integrate all these techniques into unity and encourage innovations.

Making technical innovations in petroleum production engineering as the breaking point and the development practice of Daqing Oilfield as the foundation, the author has seriously analyzed the fundamental contradictions in petroleum production engineering at the oilfields at phases of scaled establishment and production, strategy adjustment, long term production stabilization, and so on to address the scientific issues concerning high and stable petroleum production. The author used the scientific methodologies from ‘On Contradiction’ and ‘On Practice’ to discern the transition and its timing between the fundamental and subtle contradictions in petroleum production engineering that affect petroleum exploration and development, and positioned the status and bottleneck techniques of petroleum production engineering at every stage (Liu, 2013). With the organic combination of long term production practice with modern management methods and the guidance of engineering philosophy, the author built and developed a new management mode that is defined as persistent integration and innovation management mode (PIIMM). PIIMM and have effectively directed the innovation and management of science and technology in petroleum production engineering, proposed sets of new techniques, new methods, new technologies and new equipment in oil production engineering, and accelerated the development pace of new techniques and the processes of industrializing them.

2 Essences of PIIMM

Petroleum production engineering runs through the life cycle of reservoir development. Traditional technique management modes lead to the long periods and low efficiencies of the development and application of new techniques. So they fail to keep up with the fast development pace in oilfields. PIIMM breaks through the yoke of traditional management modes, upgrading managements and updating techniques in order.

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Based on the existing techniques, led by the ever-changing technical requirements in production, and guided by engineering philosophy (Wang, 2007), PIIMM breaks the traditional barriers between professions and integrates the innovative ingredients in the overall petroleum production system like intellectuals, techniques, capital, information, and so on in an organic way by focusing itself on fundamental contradictions. It accomplishes global optimization of resource configuration, creates an open and interactive innovation system in the technique management space that relatively has multiple dimensions, and accumulates sustainable momentum for collaborative and orderly development (Wang, 2005).

PIIMM singles out the objective of research and development, the systematicness of management, and the applicability of research achievement. The essences of PIIMM are insisting on the utilization and update of conventional techniques to adapt to the changes both in reservoirs and in production dynamics, the unified integration of oil production, oil reserves, well drilling and completion, and projects on the ground, the unified management of the technical system with four levels of the petroleum company, production plant, production field, and production crew, and the unified promotion of new techniques, new products, new technologies, and new standards (Wang, Wang, & Liang, 2007). PIIMM guarantees the effective, global, and collaborative development of technical innovations in petroleum production engineering over a long period.

3 Applications of PIIMM for reservoir development

After tens of years' production, oilfields in our country have some common problems. Taking Daqing Oilfield as an example, it has gradually stepped into the phase of high and ultra-high water cuts after 27 years' stable annual production of 50 million tons. The overall water cut is close to 90 percent now. It is confronted with increasing difficulty in controlling water cut to stabilize oil production and postponing the production decline (Liu, Yan, Xue, & Dang, 2004). There are two reasons for the difficulty. On the one side 80 percent of residual oil is aggregated at intermediate and low permeability zones. It is hard to implement finely separated layer water-flooding techniques as the interval between two neighboring water flow regulators in the previous separated layer water-flooding techniques is larger than 8 m. These zones have very limited and even no capacity to absorb water. On the other side a large number of pipes in oil and water wells have been damaged and even disabled due to long term production under extreme loads. Consequently, the well network is incomplete and some recoverable reserves are lost. Therefore, for old oilfields concerned by high water cuts, it is particularly important to seek a series of petroleum production techniques, of which those on finely separated layer water-flooding and the repair of casing-damaged wells and damage prevention should be the focus (Liu, 2006, 2009).

Oil reserves that needs water-flooding for production, account for 82 percent of the development, and oil produced by water-flooding, accounts for 80 percent of the total produced in China. Separated layer water-flooding techniques have achieved outstanding success with economic and efficient development, durable and stable with high production, and the improvement in the water-flooding recovery rate. Problems and the production requirements imposed on separated layer water-flooding techniques change when the development phases in oilfields shift. For heterogeneous sandstone reservoirs with multiple oil layers, conflicts between layers stand out in the late period of high water cut, and huge heterogeneities exist between oil layers, on layer planes, and within layers. Although development layers are categorized and several and even more than ten sub-layers are developed simultaneously in every well, permeability differences still exist between layers and on the layer planes. Finely separated layer water-flooding is an effective tool to develop reservoirs like these (Wang, Liu, & Deng, 2014).

Guided by PIIMM, the history of reservoir development with water-flooding and its related separated layer water-flooding techniques have been analyzed, followed by the determination to improve the techniques. These ways are to reduce the packer interval, increase testing precision, and reduce testing and adjusting. The potential of oil layers with low permeability or thin and ill-conditioned production zones is tapped by reducing the packer intervals while the balance between injection and production as well as the energy to drill oil is to be safeguarded. The testing efficiency is increased and the cost is decreased by increasing the testing precision and allocation. These ways prompt the consistent utilization and update of the traditional separated layer water-flooding techniques that in return are always ranked as the leading techniques in the world.

3.1 Innovative development of the 'two smalls and one prevention' finely separated layer water-flooding technique, removing the difficulty in making the packer interval in separated layer water-flooding techniques smaller than 8 m, and improving reserve producing degree

Problems induced by reservoir heterogeneities are increasingly apparent when oilfields step into the late production phase of high water cut. Water channeling occurs too early in high permeability zones, meanwhile low permeability zones just absorb a small amount of water and sometimes does not absorb any water. The objective from which the potential will be tapped should be switched from high permeability zones to those with low permeability, thin and ill-conditioned layers. Previous strings for separated layer water-flooding and testing technologies are only suitable to injection wells where layers are thicker than 8 m. To release low permeability, thin and ill-conditioned zones from previous layer sections and improve their water absorption capability and reserve producing degree, the limitation that the interval between two neighbor side-pocket injection allocators is larger than 8 m imposed by previous technologies of dropping, retrieving and testing should be broken. So strings for the ‘two smalls and one prevention’ finely separated layer water-flooding technique are manufactured. ‘Two smalls’ refers to small inter-layers and small packer interval, and ‘one prevention’ means the prevention of pressure transfer from high pressure zones beneath packers to overlain low pressure zones when it is measured. Great efforts have been made to settle the technical issues on strings for finely separated layer water-flooding technologies and their related testing ones. This results in the shortening of interval between two neighbor side-pocket injection allocators from 8 m to 2 m and the satisfaction of the requirement by finely separated layer water-flooding in oilfields.

3.2 Innovative development of the bridge type side-pocket separated layer water-flooding technique, solving the problem of the low precision in multi-layered testing, and improving reservoir recognition and precision of numerical simulation

The surveillance and control of pressure in the oil layers always plays an important role for effective reservoir management. The pressure in oil layers and the property of dynamic change during production cannot be revealed by overall well pressure. The new pressure measurement technology satisfies water-flooding requirements at late period of high water cut. Owing to the invention and innovative design of the key bridge type side-pocket parts and the seal section of testing, the bridge type side-pocket water-flooding and testing technique is endowed with the ability of testing flux at single or multiple layers separated by packers. The technique has a simple allocation, high efficiency, and strong functions of an instant close, test, adjustment, and block beneath wells. The techniques of single layer measurement by double packers and flow meters with small ranges reduce testing errors in the descending method and measurement errors, improve testing accuracy, and have apparent advantages for injection wells having low inflow at single or multiple layers. They make excessively effective and accurate separated layer pressure tests, satisfying the testing requirements on magnetic positioning, seal checking, pressure measurement, profile of isotope suction, and so on. They can obtain 25 items of dynamic and static layer-separated data and have shown excellent application effects in oilfields.

3.3 Innovative development of the bridge type side-pocket, steel cable-based direct measuring, testing-adjusting-interacted, and separated layer water-flooding techniques, solving the problem of downhole operators having tough operation and low operating efficiency, and improving system production logging accuracy and efficiency

In the traditional steel wire-based dropping, retrieving, testing, and adjusting technology, steel wire is the only link that connects infrastructure on the ground with that underground. It is only by dropping down a hole memory type flow meter at every target layer with steel wire that the injection is measured, and it is also only by drawing the flow meter to the ground with steel wire and running it back that testing results are obtained. In most cases, flux adjustment by dropping, retrieving, testing, and figuring relies on experience. Therefore, operators who work on dropping, retrieving, testing, and adjusting with steel wire are faced with tough operation and an overlong working time. In addition, for nozzles with fixed and discontinuous grade gap, the gap of inside diameter equals 0.2 mm, leading to the difficulty in the satisfactory control of separated layer water-flooding.

By building the relationship between ground control as well as the downhole test and the inside nozzle diameter of controllable and adjustable plugs, the testing function and the function of adjusting the inside nozzle diameters of adjustable plugs are seamlessly incorporated into the same downhole instrument, and the testing-adjusting-interacted technology where testing and adjusting are synchronized comes true. Furthermore, the adjustment part of the downhole testing and adjusting instrument can control the nozzle closing and opening via ground operation orders, the instrument can reach any position of separated layer water-flooding strings instantly, and ultimately the control of water-flooding into sub-layers in a whole well can be accomplished by the instrument once for all. For a well with separated layer water-flooding, it takes the new and highly effective bridge type side-pocket technology only 1 to 2 days to test and adjust the instrument if the well has three layer sections and is 1000 meters deep. Compared with the traditional steel wire-based dropping and retrieving technology, the new technology can reduce the operation to a large extent and apparently improve testing and adjusting efficiencies.

3.4 Innovative development of multi-disciplinary techniques for the repair and damage prevention of casing wells, solving the problem of an incomplete well network, and improving the capacity of precise water injection

Synthetic treatment of casing-damaged wells covers a couple of disciplines. Damage modes have been studied by measuring borehole diameters with multiple arms, followed by calculating their ratios. Based on the study of casing damage modes, statistical investigations of the life span of case-damaged wells, the extent and special distribution of casing damages, and soon have been carried out, and the distribution laws of casing damages have been found. Based on the statistics, a picture for global comparison and analysis of casing damages has been drawn; the geological causes that govern casing damages have been discussed by analyzing faults, geologic stratum, lithology, and so on. A geological model for casing damages has been built, and the internal causes that govern casing damages have been recognized. Based on dynamic development data, the effects of water injection pressure, water cut, development manners on casing damages have been analyzed. The development causes that affect casing damages have been screened, resulting in the discovery of the external causes on casing damages. The engineering causes like overall angle change rate of drilling, casing steel grade, wall thickness, the quality of well cementation, and have been analyzed. The engineering defects that have impact on casing damages have been discerned. A mechanical casing damage model has been set up and the mechanical conditions for the occurrence of casing damages have been analyzed on the basis of considering the geologic, development, and engineering causes. Finally, measures for the repair of casing-damaged wells and casing damage prevention have been proposed, and these measures have been put into practice in oilfields. Eight techniques and methods on casing damages have been integrated and innovated, including the multi-disciplinary detection of casing damage modes, the statistical analysis of the characteristics of casing damages, the setting up of geological model for casing damages, the analysis of governing development and engineering factors, the simulation of casing damage distribution controlled by ground stress, the building up of geomechanical model for casing damages, the comprehensive prevention from casing damages, and so on.

Based on the investigation of casing damage mechanisms, well repair related techniques and technologies covering releasing stuck, fishing, canal driving with small inside diameter strings, sealing and reinforcement, case pick-up and replacement at depth, skewed drilling, declaration of engineering abandonment, and soon have been studied and further developed in terms of casing damage characteristics at every period. The techniques have grown into the comprehensive treatment-dominated ones from the initial maintenance-dominated ones. These techniques and technologies continually make the network of development wells complete, extend the lives of production wells, increase the capability of precise water injection, and enhance the global economic benefits of development in oilfields.

4 PIIMM accomplishing effective, global, and cooperative development of the management of production techniques in oilfields over a long period, resulting in significant economic benefits

PIIMM takes the industrial application of advanced techniques as the standard to appraise innovations (Duan, Yu, Yang, & Duan, 2014; Ye, 2014). It has constructed a complete innovation chain from top design, fundamental research, technique research and development, testing and promotion, to industrial application, formed the route and technical tree for the development of petroleum production techniques, and made technique management modes effective, global, and cooperative over a long period. PIIMM has directed technique breakthroughs to run in a global, orderly, and highly effective way, and accelerated the upgrade and replacement of key techniques in petroleum production engineering. PIIMM has developed and perfected the technique tree comprised by fifty-five new techniques from ten classes including separated layer water-flooding and stimulation by hydraulic fracturing. PIIMM has propelled the concretization of these techniques and their scale-up of application, solved the problems of technique upgrades not matching the changing production needs at development phases in oilfields, and achieved great economic and social benefits.

By the end of 2014, the finely separated layer water-flooding techniques had been used in 10,705 wells in Daqing Oilfield. The annual number of times using this technique amounted to 20,000 times, the oil recovery rate had increased by 3 percent, the production of crude oil had increased by 1.273 million tons, and the production of water had decreased by 330 million cubic meters. They played a critical role in stabilization the production on the oilfield. The finely separated layer water-flooding technique not only has been applied at an industrial level for domestic oilfields, but also has been popularized abroad in Kazakhstan, Indonesia, Sudan, and so on. These techniques have created tremendous economic benefits. Journal of Petroleum Technology, which is a world-renowned magazine in the petroleum industry, has reported the testing-adjusting-interacted and separated layer water-flooding technique in this article and it was promoted throughout the world.

Via technical innovations, a couple of new techniques and equipment on casing repair have been developed, breaking through the technical bottleneck of a low repair rate in narrow channel and casing-damaged wells. A management support system has been developed to prevent and delay casing damages, making true the unification of prevention and repair and resulting in the uniform treatment of superficial and essential problems. Project management on vast repair engineering has been carried out in Daqing Oilfield. There were 19,933 wells repaired in the last ten years, of which there were 6433 with casing-faults. The success rate of their repair climbed to 80 percent from the initial 40 percent. The availability of water and oil wells was improved, leading to less drilling and renewing of wells by 117 and the reduction of investment by 220 million CNY annually on average.

5 Conclusions and prospect

PIIMM in petroleum production engineering is an innovative mode, resulting from the continual conclusion and sublimation during the long term production practice. This mode has solved various problems encountered during the innovation of science and technology, made true the organic integration of key constituents like intellectuals, techniques, capital, information, and so on, satisfied the requirement on the technical innovation for crude oil production, and enhanced the management on science and technology.

With continuous changes of oil and gas production situations and increasing requirements on techniques, PIIMM will continue to expand by integrating deeply with new materials, big data, network plus, and so on, extending its application to serve the research, development, and layout of new and advanced techniques in the next generation. In the national 863 breakthrough project of Key Techniques and Equipment in the Governing Engineering of Oil Wellbore, PIIMM will reinforce the organization, management, and the practice of innovation methods, guiding the separated layer water-flooding techniques to develop and move forward towards automation, intellectualization, and unification. PIIMM will continue to lead the powerful tools of new techniques and equipment in petroleum production engineering and chase innovative breakthroughs, supporting the sustainable development of petroleum industry in our country.

References

Duan, Y., Yu, D., Yang, L., & Duan, Y. (2014). Research on the dynamic identification mechanism of innovative enterprise's sustainable innovation opportunity. *Forum on Science and Technology in China*, 6, 70–76

Liu, B. (2008). *Encyclopedia of petroleum exploration and development in China–engineering*. Beijing: Petroleum Industry Press

Liu, H. (2006). Breakthrough of techniques to provide the sustainable development of Daqing Oilfield with production engineering support. *Petroleum Geology & Oilfield Development in Daqing*, 25, 23–27

Liu, H. (2009). The challenge and technical trend of petroleum engineering in Daqing Oilfield. *Petroleum Geology & Oilfield Development in Daqing*, 28, 186–191

Liu, H. (2013). Enhancing the management of oil production engineering with philosophical thinking. *Engineering and Science*, 15, 31–35

Liu, H., Yan, J., Xue, F., & Dang, H. (2004). Status quo and future development of production engineering at high water cut state in Daqing Oilfield. *Petroleum Geology & Oilfield Development in Daqing*, 23, 65–67

Wang, Y. (2005). Science and technology support for an oilfield to develop 100 years. *Chinese Petroleum Enterprise*, 9, 24–27

Wang, Y. (2007). Self-dependent innovation to create one hundred years' brilliance–practice and cerebration for the strategy of building one hundred year's Daqing oilfield. *Qiushi*, 15, 56–58

Wang, Y., Liu, Y., & Deng, Q. (2014). Current situation and development strategy of the extra high water cut stage of continental facies sandstone oil fields in China. *Journal of Northeast Petroleum University*, 38, 1–9

Wang, Y., Wang, J., & Liang, S. (2007). Management of self-dependent science and technology innovation in Daqing Oilfield. *Chinese Petroleum Enterprise*, 3, 109–114

Ye, L. (2014). Methodology of sustainable development for enterprises-reading of 'Dealing with Darwin: how great companies innovate at every phase of their evolution' written by Geoffrey A. Moore. *Modern SOE Research*, 7, 90–96