Energy 89 (2015) 259–267

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Review on application of the recent new high-power ultrasonic transducers in enhanced oil recovery field in China

Zhenjun Wang*, Yuanming Xu

School of Aeronautic Science and Engineering, Beihang University, Beijing 100191, China

ARTICLE INFO

Article history:
Received 28 September 2014
Received in revised form
13 July 2015
Accepted 14 July 2015
Available online 10 August 2015

Keywords:
Ultrasonic oil production technique
Ultrasonic transducers
Enhanced oil recovery

ABSTRACT

Ultrasonic oil production technique is characterized by high adaptability, simple operation, low cost and zero pollution. In this paper, the recent new high-power ultrasonic transducers for Enhanced Oil Recovery field in China are summarized. The application of high-power ultrasonic transducers for Enhanced Oil Recovery are also introduced in the view of preventing paraffin precipitation by ultrasonic wave, ultrasonic crude oil viscosity reduction, ultrasonic demulsification/dehydration, removing plug using ultrasonic wave and ultrasonic descaling/anti-scaling. Finally, installation speculations and operable speculations for ultrasonic oil production in offshore oil fields are given. the purposed of this paper is to provide important process parameters and technical support for future large-scale application of ultrasonic oil production technique.

1. Introduction

In recent years, oil recovery remains to be a challenge in the world. Currently, most countries and regions in the world commonly use chemical method to increase oil production of the middle and later stage oil wells. Application of these methods is usually limited by the cost of the chemicals and their adsorption and loss onto the rock of the oil containing formation, and the most direct consequence is causing environmental pollution and making the surface of the earth into desertification. As one of Enhanced Oil Recovery techniques [1,2], ultrasonic oil production technique can effectively avoid these drawbacks. Furthermore, it has other several advantages, such as high adaptability, simple operation, low cost and zero pollution.

Conventional chemical method is actually injecting the polymer chemical into the reservoir to enhance oil displacement effect. Different oil reservoir conditions and the crude oil property need different polymer chemical, furthermore, only after periodic tests can make sure whether the prepared polymer chemicals are available. The long-term use of polymer chemicals can not only pollute the oil reservoir, but also reduce oil recovery. Ultrasonic oil production technique is to make ultrasound wave directly acted on the oil reservoir, therefore, there is no oil reservoir pollution problem. From the view of the equipment cost, one polymer injection device needs $230,000–$27,000, while an ultrasonic oil production device only needs $32,000–$97,000 [3]. From the view of effective stimulation period, the effective stimulation period of acting on oil well by polymer chemical injection device is at least 4 months and up to 7 months, while that of ultrasonic oil production technique is at least seven months and up to 15 months. It is easy to see that ultrasonic oil production technique is better than conventional chemical method no matter in terms of equipment investment or adaptable ability.

China is the third country, following the United States and Russia, that masters the ultrasonic oil production technique, and has made great progress in this technique through decades of development.

2. The development of high-power ultrasonic transducers

The core part of ultrasonic oil production equipment is high-power ultrasonic transducer. Therefore, how to design high-power ultrasonic transducer that satisfy the practical requirement is one of the critical factors that determines EOR technology success [4]. The influence of ultrasonic frequency on the radiation impedance of ultrasonic transducer used in oil production is systematically studied by Wang Yangon et al. [5]. The radiation impedance of the ultrasonic transducer used in oil production is calculated according to the wave functions and the boundary conditions. In addition, the influence of ultrasonic frequency on the radiation impedance of ultrasonic transducers used in oil production is

* Corresponding author.

http://dx.doi.org/10.1016/j.energy.2015.07.077
0360-5442/

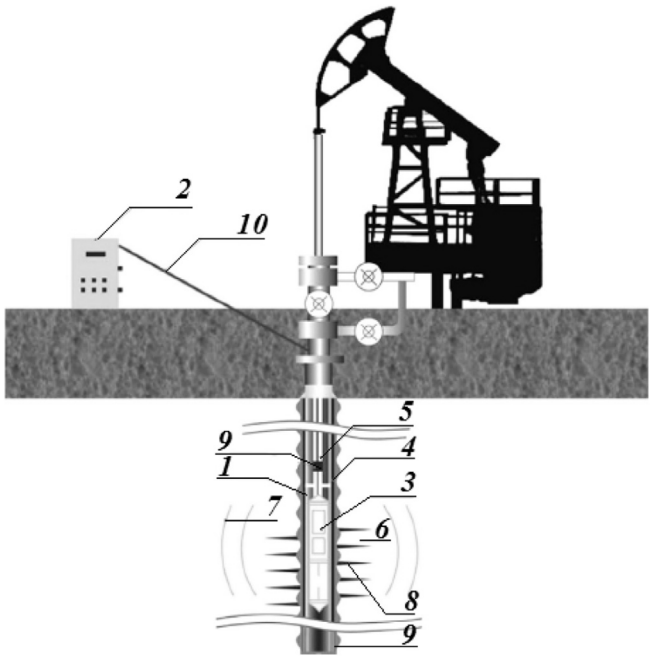

Fig. 1. The composition of CSYY60H10 type complete sets of equipment for high power ultrasonic oil production [5]. 1-anchor, 2-ultrasonic generator, 3-downhole tool, 4-casing, 5-tubing, 6-producing formation, 7-ultrasonic field, 8-perforated zone, 9-sucker-rod pump, and 10-power cable for the downhole tool.

discussed under different conditions. Under the conditions of different well fluid velocity and different ultrasonic radius, the effect of transducer frequency on the radiation impedance is relatively large, while the transducer frequency has little effect on the radiation impedance under the condition of different rock sound velocity and different density. Therefore, when designing a transducer, size of the radius of the ultrasonic transducer and the change of the fluid velocity should be fully considered.

One transducer for EOR technique—PSMS-42 has been introduced in detail by M.S. Mullakaev [6]. The ultrasonic transducers manufactured from permendur plates have a vibration resonance frequency of 19.963 kHz. The composition of PSMS-42 type complete sets of equipment for high power ultrasonic oil production and Schematic diagram of this transducer are shown in Figs. 1 and 2 respectively [6]. On the basis of the above transducer, a high-power ultrasonic oil production equipment—CSYY60H10, shown in Fig. 3, was developed jointly by Drilling Technology Research Institute of Shengli Petroleum Administration Bureau and Harbin Rand ultrasonic equipment Co. Ltd [7]. This equipment is composed of reservoir positioning system and ultrasonic processing system. The later mainly consists of ultrasonic power, low loss special cable for ultrasonic oil production, special bridle and underground ultrasonic transducer. After starting the equipment, the ground ultrasonic power source emits about 20 KHz ultrasonic electric power, it is transmitted to the underground ultrasonic transducer by ultrasonic oil production special cable and ultrasonic work special bridle, then this electric power is converted into sound power by ultrasonic transducer, this sound wave through fluid coupling into stratum. After ultrasonic oil viscosity reduction and ultrasonic plug removal. The remaining oil can be mined.

Technical characteristics of this ultrasonic transducer are as follows:

(1) Low loss special cable for ultrasonic oil production. The sections of this special cable are, in order, inner conductor, main insulation layer, outer conductor, waterproof insulating layer and amour steel wire from inside out. Inner conductor consists of stranded enameled wire, main insulating layer is made of special polypropylene, outer conductor is a shielding net structure woven by bare copper wires, waterproof insulating layer is made of butyronitrile rubber, transmission efficiency of this special cable is much higher than ordinary cable;
(2) Ultrasonic special bridle. This new special bridle consists of interface armored with steel for connecting special cable, isolator and plug-in connector. The upper end of this special bridle is connected with the cable bridle; the lower end is connected with underground ultrasonic transducer. The innovation is that plug-in connector is designed using the medium sized plug and socket structure and 100A explosion-proof electric connector.
(3) Underground ultrasonic transducer. The piezoelectric vibrator is the core part of the transducer, which is made of a new piezoelectric material-lithium neonate crystal that has better piezoelectric properties than common piezoelectric materials-Piezoelectric ceramic.

Practices prove that this equipment can effectively increase the crude oil production and reduce the environment pollution. The

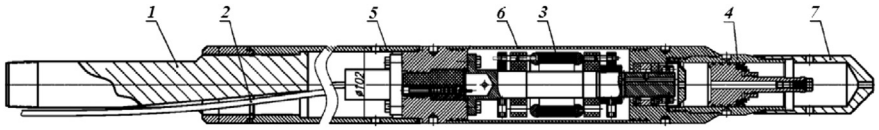

Fig. 2. Schematic diagram of general structure of underground ultrasonic transducer [5]. 1-reducer NKT-60, 2-cable lug, 3-magnetostrictive radiator, 4-hydrocompensator of excess pressure, 5-housing of the tool, 6-housing of the magnetostrictive radiator, and 7-tip.

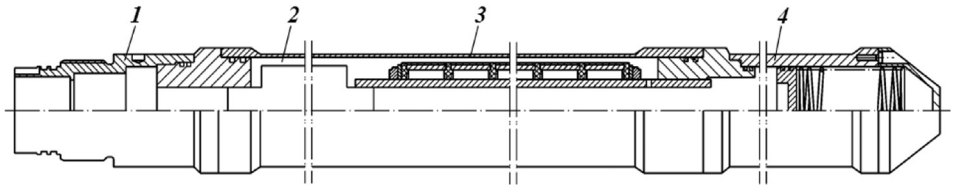

Fig. 3. Schematic diagram of general structure of underground ultrasonic transducer. 1-the upper connector, 2-inductance matching section, 3-sound wave radiation section, 4-pressure balancing section.