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The optimization approach of casing gas assisted rod pumping system

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ABSTRACT

The free gas evolved in the pump chamber results in a low rod pump working efficiency, and it can even lead to a failure. A common and effective solution is to install a downhole gas separator before fluid entering the chamber, which can divert the free gas to the annulus. If we can re-inject the diverted gas back to the tubing at a shallower depth above the pump, the flowing gas is then re-combined with the liquid and decreases fluid density. Consequently, the injected gas also creates additional lifting drive for the liquid. A new technology based on this concept has been developed and called Casing Gas Assisted Rod Pumping (CGARP). This paper firstly presents an analytical model to optimize the overall lifting performance and minimize the operating expenditure. It is especially useful in producing hydrocarbon at high GOR.

As the gas is re-combined with the liquid above the pump installation depth, the hydrostatic pressure gradient is reduced consequently. However, if the gas reinjection valve is placed at a shallow depth, the well segment at reduced fluid density is subsequently short, so the contribution of gas lift is restricted. Vice versa, if the gas reinjection valve is placed at the depth close to the pump, it requires high pressure to open the gas injection valve, so the gas reinjection can happen infrequently and the production rate is unsfplease. This paper has proposed a genetic optimization method to maximize the overall production system efficiency. A multi-variable vector has been defined, which includes pumping speed and depth, mechanical power, rod string diameter and length, surface stroke length, downhole separator efficiency, as well as gas reinjection valve depth. The optimized object can be the system lifting efficiency or Net Present Value, which must be a function of this vector in the constraint of mass and momentum conservations.

This work has been applied as the primary guide for four oil producers with rod pump installed in Jilin field, China. The average system lifting efficiency and production rate have been increased by 20% and 15% respectively. This analytical model has enhanced the field performance. Most importantly, the same concept can be applied for other pump-assisted wells.

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1. Introduction

For oil fields with high GOR, gas lift method can be an ideal candidate (Redden et al., 1974; Herald, 1987). However, because of the high capital expenditure, limitation of available gas, and complexity of the surface system, the rod pumping system has been generally adopted in field. On the other hand, for the high GOR fluid, the release of solution gas inside the rod pump can notably deteriorate its working performance. As an effective and common solution, the Downhole Gas Separator (DGS) or anti-gas pump can restrict the free gas entering the pump and thus improve the pump efficiency (McCoy and Podio, 1999; Dottore, 1994). Unfortunately, the separated gas is usually discharged through the casing, and later mixed with the liquid flow lines at surface. As a result, the energy of this casing gas is not utilized above the pump setting point.

A new concept of Casing Gas Assisted Rod Pumping (CGARP) system has been introduced earlier (Liu et al., 2007). The free gas separated after DGS can be re-injected from the annulus into the tubing above the pump installation depth. After re-combining the gas with the liquid, the fluid density is reduced. Thus, the producer can have an enhanced production rate in the favor of both pump- and gas-lift assistances, as shown in Fig. 1. The Casing Gas Assisted Rod Pumping (CGARP) technology utilizes the natural gas

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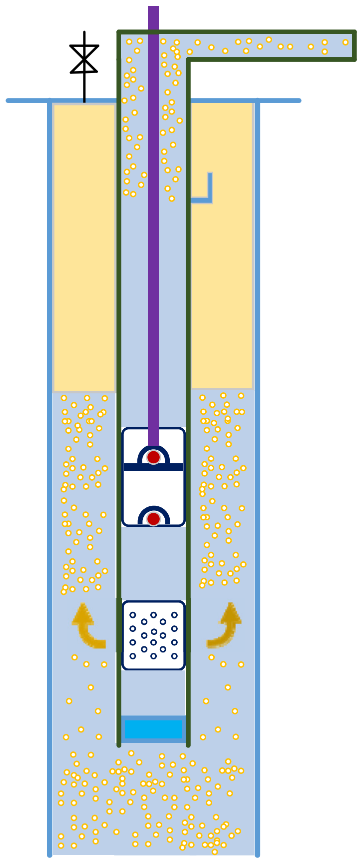

Fig. 1. Structure of CGARP.

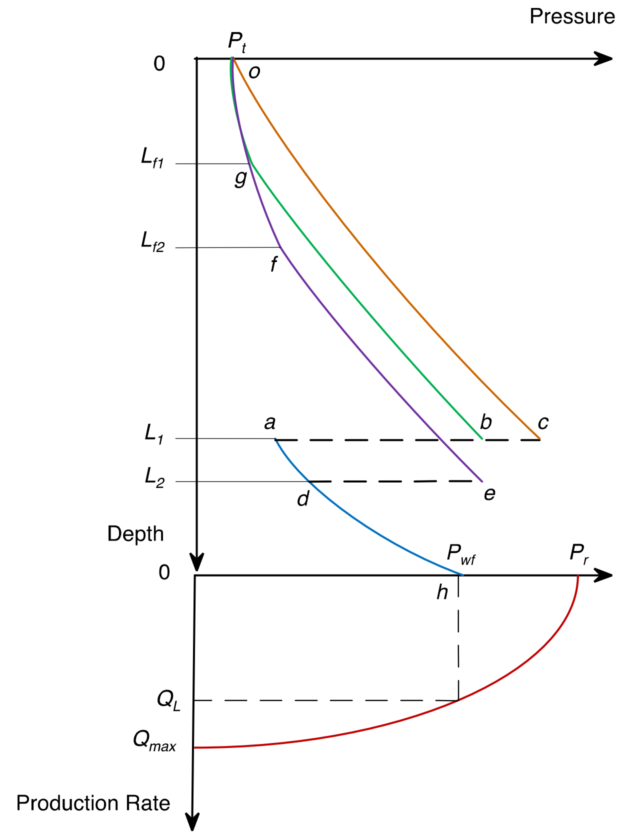

Fig. 2. Pressure profiles under different conditions.L_f represents gas valve placement depth; L represents pump depth; *oc, ogb, ogfe, and adh* are the pressure gradients representing different pump or gas valve setting depths.

expansion to lift the oil to surface. It can be applied in high gas-oil ratio wells, coal-bed-methane well, and liquid-loading wells.

The CGARP system consists mainly of a rod pump, a DGS, a gas lift valve, and tubing strings. The gas injection valve is open once the annulus pressure has built up over the valve closure pressure. Once the free gas is released to the tubing and the injection valve is closed, the annulus becomes a closed system. The free gas continuously exits from the DGS, which gradually pressurizes the annulus, until the valve can be open again as the next cycle. This mechanism indicates an intermittent gas lift process. This technology is different from the conventional gas lift wells whose injected gas is through wellhead (or from surface), which means the compressor is at the surface. The CGARP system utilizes the expansion energy of the produced gas (through downhole separator) from the same well. The gas bypasses the pump. It accumulates within the tubing-casing annulus and flows back to tubing in a shallower depth to lift liquid as shown in Fig. 1.

As the gas is re-combined with the liquid above the pump installation depth, the hydrostatic pressure gradient is correspondently decreased. In another word, the hydraulic pressure gradient changes from the orange line "*oc*" to the lines "*ogb*" or "*ogfe*" in Fig. 2; meanwhile the working load at the polished rod is varied. Further, if the gas reinjection valve is placed at a shallow depth, the well segment at reduced fluid density is consequently short. For example, if the valve depth is L_{f1} in the Fig. 2, the well segment with contribution of gas lift is a restricted length "*og*". Vice versa, if the gas reinjection valve is placed at the depth close to the pump, it requires high pressure to open up the gas reinjection valve, so the gas reinjection can happen infrequently. In the Fig. 2, if the valve is place deeper at L_{f2}, the gas lift contributed well length is "*ogf*". In other words, if the pump is place in the deep depth (from *a* to *d* in the Fig. 2), the annulus pressure can be high, so the gas valve can also be placed in the low position. An optimization point for the pump and gas valve setting depth is required.

All these transient impacts are related to the injection frequency and rate, which should be investigated by all means including cashflow and safety consideration. In the favor of one-way flow gas valve, an automatic controlling mechanism is also desired. Although CGARP method has been derived from field experience, this practice has missed theoretical guidance.

To propose the analytical model for CGARP, frontline modeling efforts in optimizing rod pump and gas lift wells are required. API method (API RP11L, 1977), based on the measured production rates and required power supply, is one of the analytical methods in optimizing the rod pump lifting system with high recommendation. By solving the wave equation, Gibbs (1977, 1982) predicted the dynamic behavior of rod pumping system and presented the related simulation models. Podio and McCoy (1999) established a new model of rod pumping system with achieving the lowest energy consumption. Brown (1986) summarized the optimization methods of gas lift. Betancourt et al.(2002), Bedrin. et al.(2008), and Nagib et al.(2010) discussed the principle of enhancing pump efficiency with using fluid assisted lifting technology.

To the best of the authors' knowledge, for this newly emerging CGARP system, the optimization method has not been proposed in literature. The analytical model presented by this work can achieve the maximum cashflow for operators.

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