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Study on the replacement time of velocity string in production process in tight gas reservoir

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ABSTRACT

Tight gas reservoir production processes have many challenges, one of which is liquid loading. Installing coiled tubing velocity string (VS) can be an effective tool to extend the production life cycle, and to increase gas recovery. This study focuses on the Daniudi tight gas reservoir in the Northern Ordos Basin, China, as an example of VS application. The basic information and production characteristics of VS wells were firstly analyzed. Then, an evaluation process of VS production effect was established, and the effect after VS installation was divided into three types. The evaluation indexes included water flooded in well, the declining of production rate, the change of cleanup measures and the increasement of the gas–liquid ratio. At last, two methods were used to determine the optimal time to replace the tubing with VS. The first method was a statistical approach, which calculated VS replacement time was no more than 700 days in Daniudi tight gas reservoir, this occurred when the tubing head pressure was more than 6 MPa and the gas–liquid ratio was 0.50–3.00 $\times$ 10^4 m^3/m^3 before VS installation. The second method was a theoretical calculation, in which the critical liquid carrying capacity was higher than the daily gas production, and the corresponding time was the time to incorporate VS. The critical liquid carrying capacity of the calculation model was divided into three parts: the vertical section, the horizontal section and the inclined section. Through calculation analysis, the critical liquid carrying flow rate of the inclined section became the critical flow rate of the well. The actual replacement times of wells were compared with calculated replacement times, to show the validity of the method used in this study.

1. Introduction

Liquid loading has increased in popularity with the development of tight gas reservoirs. Coiled tubing (CT) is often used as a production string in shallow gas wells that produces some water. The narrow internal diameter of these tubes results in a higher velocity than would normally occur inside conventional tubing, or inside the casing. When CT is run inside conventional tubing it is often referred to as a velocity string (VS), and the space between the outside of the CT and the inside of the conventional tubing is referred to as the micro annulus. In some cases gas is produced from the micro annulus. Installation of a small diameter VS is often necessary in tight gas wells to resolve liquid loading problems. Incorporating VS has previously been documented as a successful remedy for liquid loading (Weeks, 1982; Harms, 2009; Poppenhagen et al., 2010). Selection of the correct string size is critical; when the flow conduit size is too small production is unnecessary restricted, and when the string is too large the beneficial effect of installing the string will be short lived (Oudeman, 2007).

Recent research has focused on the application of VS in the production field. Goedemoed et al. (2010) described the first VS trials undertaken in the Oman deep gas field, the inflow/outflow modeling and the main operational challenges encountered. Chavez (2011) recognized that if the clean-out and VS placement could be achieved in a single operation, without killing the well, that costs would be saved and the risk of well impairment would be reduced. VS trials were assessed and significant appraisal activities were investigated from 2005 to 2009 in the contingency resource areas in the main Sultanat of Oman gas field (Busaidi et al., 2012). Asel et al. (2014) provided a case study of a retrograde gas condensate well and the challenges encountered during the successful implementation of an engineered approach with the aid of In-Well Live Performance to successfully select and deploy VS for gas well deliquification.

Some researchers studied on the liquid loading. Turner et al.

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(1969) proposed the first critical rate calculation procedure to predict liquid loading, and the entrained-droplet model is the most popular one in predicting liquid loading in gas wells. Coleman et al. (1991) applied the entrained-droplet model to their well data, and obtained satisfactory results. Coleman suggested that Turner's 20% upward adjustment was unnecessary for gas wells with low-gas rates and low-wellhead pressures. Unfortunately, Coleman provided the dataset from gas wells with very low wellhead pressures, which suggested that the wells were already dying. Zhou and Yuan (2010) stated that liquid holdup is the third mechanism that causes liquid loading, and proposed two models separated by the threshold liquid-holdup values. Further research on liquid loading has been undertaken (for example Alamu, 2012; Belfroid et al., 2008; Dousi et al., 2006; Hu et al., 2010; Lea and Nickens, 2004; Sarica et al., 2013) and many solutions have been proposed for this problem. In China, a new formula for calculating the minimum liquid-carrying velocity and the production rate for continuously withdrawing liquid from a gas well was derived by adopting a new view point that the moving-up liquid droplet carried by the gas flow in gas wells tends towards a flat shape (Li et al. 2001). Other researchers have studied the critical liquid carrying capacity of gas wells (Lei et al., 2010; Wang and Li, 2012).

The Daniudi gas field has low permeability so hydraulic fracturing is required to establish economic production. As the reservoir pressure depletes and the flow rates decline, water loading results in production deferment and the loss of reserves. A low success rate for foam scrubbing exists in the horizontal wells of the Daniudi gas field, due to the effect of the wellbore structure. Discharging fluid is a difficult task, however, and the replacement of small tubing requires the well operation to cease. The flowback cycle is also long and leakage is large. As a result, the reservoir is substantially polluted and the production capacity of the wells is severely restricted. In consideration of the horizontal well feature in the Daniudi gas field and the difficulty in water drainage and gas recovery, VS installation are developing quickly. The first VS well in this gas field was at DPS-5 which was established on January 30th, 2013.

In this study, we will describe the basic information and production characteristics of a VS well in the Daniudi gas field. VS installations are usually considered when low gas production and serious liquid loading problems occur. To study VS replacement of tubing in the production process, the Daniudi tight gas field will be used as an example. A statistical method and a theory calculation method will be used to estimate when tubing in certain wells in this field require replacement with VS installations.

2. Daniudi tight gas field

Daniudi gas field, a low-porosity and low-permeability tight sand gas reservoir, is located on the Ordos Basin. By the end of 2014, the cumulative gas production of the site was 22 billion cubic meters. The Daniudi gas field is characterized by high actual stress, high matrix capillary, low porosity and low permeability (Lan et al., 2010). The average porosity is 8.01%, and the permeability is 0.175 ~ 1.8 mD, with the average value being 0.9875mD. The effective thickness is 2.26 ~ 60 m, with an average thickness of 31.13 m. The gas saturation is 0.21 ~ 0.79 with an average value is 0.5 (Li et al., 2014). The Daniudi gas field, therefore, is a low-porosity, low permeability and high water saturation, lithological reservoir (Zheng., 2010).

Large-scale horizontal wells were developed in the Daniudi gas field in 2012. The natural production is very low, and multi-fractured technology is widely used in the horizontal wells. The main producing horizons are S2 and H1. Data from the 116 wells shows that the length of the horizontal wells is 578 ~ 1501 m, with an average length of 1125 m.The number of fractures is 4 ~ 17, with an average value is 9. The flowback rate is 15.87% ~ 90%, with an average value of 52.84%. The absolute open flow (AOF) is 1.4 ~ 48 $\times$ 10^4 m^3/d, with an average of 8.79 $\times$ 10^4 m^3/d. Table 1 shows part of the data for the horizontal wells in the Daniudi gas field.

3. Production characteristic of VS well in Daniudi gas field

There are 116 wells in the gas field, 60 wells were fitted with VS installations and the production data was used for this study. The production formations were H1, S1, S2, T2 and M5. The collected data included pressure, gas production and liquid production. Table 2 shows the records for these parameters before and after VS installation.

The average gas production was 2.47 $\times$ 10^4 m^3/d before VS installation, and 1.91 $\times$ 10^4 m^3/d after VS installation; Gas production reduced by 22.66%, on average, after the installation of VS. The average liquid production was 3.47 m^3/d before VS installation, and the value was 2.74 m^3/d after VS installation. The liquid production reduced by 20.97%, on average, after using VS.

The well production effect after VS installation can be divided into three types: good effect, general effect and poor effect. Fig. 1 shows the evaluation process of the production effects.

To facilitate the above four steps, the evaluation indexes of each step were established. The indexes of the first step were the average critical liquid carrying capacity and gas production. If gas production is greater than the critical liquid carrying capacity, then no water out will occur. The index of the second step is the production rate. A decreased production rate indicates a poor effect. The last two indexes are the increasement in clean-up measures and the improvement of the gas–liquid ratio. In order to explain the flow chart step by step, well DPS-46 was taken as an example. It was put into operation in November 11, 2013. The average daily gas production was 2.22 $\times$ 10^4 m^3/d before VS was installed, and the VS was installed from December 3rd to December 5th, 2013. The well was not

Table 1
The statistics data of Daniudi gas field.

Well	Horizontal length (m)	Number of fractures	Flowback rate (%)	AOF (10^4 m^3/d)
DPH-16	1200	11	27.58	8.09
DPH-20	1500	13	68.75	12.07
DPH-41	1213	12	42.39	29.13
DPH-69	1200	9	32.40	12.34
DP32H	1000	9	78.60	6.38
DPT-2	1200	11	41.63	11.24
DPT-16	1000	10	48.60	4.52
…	…	…	…	…
Average	1125	9	52.84	8.79