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Full Length Research Paper

Parametric design and application of fibreglass reinforced plastic tubing in beam pumping wells

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A pragmatic and efficient technique has been developed to perform parametric design for the downhole fibreglass-reinforced plastic (FRP) tubing with successful applications in beam pumping wells. More specifically, hydraulic tubing anchor has been adopted to minimize stretch and recoil of the FRP tubing, while steel tailpipe is used as a counterweight to reduce the axial compression. In lieu of the rough steel rod couplings, wear-resistant rod couplings with smooth surface are utilized to avoid friction damage between the FRP tubing and the rod string. It has been found from five test wells that such parametric design significantly mitigates eccentric wear between the rod string and the tubing together with tubing corrosion. The average pump efficiency of for the five test wells is found to be 74.5%.

Key words: FRP tubing, beam pumping well, corrosion, eccentric wear, tubing anchor, rod-coupling.

INTRODUCTION

When water cut is steadily increased in a mature oilfield, eccentric wear between the rod string and tubing becomes more and more serious in the beam pumping wells, leading to severe erosion of the tubing. Meanwhile, produced fluids normally contain dissolved oxygen, sulfate reducing bacteria, CO_2, and H_2S, which can seriously corrode the steel tubing. Although there exists no simple superposition between eccentric wear and corrosion, corrosion will accelerate the eccentric wear of the tubing and the rod string (Philip, 2003). Numerous attempts have been made to mitigate the eccentric wear of the tubing and rod-string in beam-pumping wells by adopting centralizers, wear resistance pair, coated sucker-rod (Ryan et al., 1988) and polyethylene-lined tubing (Eric et al., 1998; Wang et al., 2008). On the other hand, the corrosion problem has been treated by adding corrosion inhibitors into annuls, utilizing cathode protector, improving quality of metallic tubing materials, for example, nickel-phosphorus plating tubing and nitriding tubing, (Siegmund, 1997). Therefore, it is of practical and fundamental importance to develop viable techniques for improving pump efficiency in beam pumping wells by mitigating both eccentric wear and corrosion. In the past 50 years, the FRP pipes have been applied to various sectors in the oil and gas industry, such as line pipes, water management systems, downhole tubings, water and chemical storage tanks, gratings and hand rails, cable trays, and many others (Williams, 1987). The major advantage of the FRP pipe is the excellent corrosion resistance associated with transporting and storing corrosive fluids and high salinity water (Cowley et al., 2004; Scott et al., 2007).

Due to its high abrasive resistance, the FRP pipe has found its application in the area of transporting liquid and/or gas containing solid particles (Hall, 1999). Recently, the FRP tubing has been employed to mitigate the eccentric wear and corrosion in the beam pumping wells, though pump efficiency remains low due to its large deformation resulted from alternatively liquid loading and unloading. In addition to its strong resistance to acid, alkali, and slat, the FRP tubing imposes a small friction to the steel rod string due to its smooth surface with a good degree of hardness. Since the elastic modulus for the FRP tubing is much smaller than that of the conventional steel tubing, stroke loss becomes larger due to the fact that the elastic deformation is proportional to the external forces (Zhang, 2000). In a vertical well, the FRP tubing

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Table 1. Physical properties of the anhydride FRP tubing.

Pressure rating (MPa)	Inner diameter (mm)	Outer diameter (mm)	Wall thickness (mm)	External collar diameter (mm)	Rated tensile strength (kN)	Ultimate tensile strength (kN)
20	62.0	82.4	10.2	108.0	150.9	317.5

undergoes an increasing axial compression imposed by the hydraulic fluid column inside the wellbore as setting depth is increased. Also, inner wall of the FRP tubing can be damaged by the movement of rough steel rod-coupling inside the tubing. As for the downhole FRP tubing, Stringfellow (1987) detailed necessary procedures for implementing the field-scale operation, while a large number of its successful applications have been achieved in injection wells (Romera et al., 2008) and hydraulically fractured wells (Peralta et al., 2006), respectively.

It has been found that the physical and chemical properties of the FRP tubing are not affected by CO_2 (Arian, 1996). Numerous efforts have been made to improve the performance of the FRP sucker-rod string. For example, Gauchel (1985) examined mechanical performance of fibreglass laminates for sucker rod applications, while Hicks (1986) attempted to apply fibreglass sucker rods in deep wells. So far, few attempts have been made to systematically address the eccentric wear associated with the FRP tubing in beam pumping wells. In this paper, a pragmatic and efficient technique has been developed to perform parametric design for the downhole FRP tubing with successful applications in beam pumping wells. Theoretical analysis of the stroke loss associated with the FRP tubing is firstly proposed. Then, detailed parametric design procedure has been provided to improve performance of the FRP tubing. Such parametric design significantly mitigates eccentric wear and corrosion between the rod string and the tubing for more than five wells.

THEORETICAL FORMULATION

In a beam-pumping well, fluid load exerts on the sucker rod during upstroke movement, but acts on tubing during down stroke movement. As such, the rod string and tubing are loaded and unloaded with fluids alternatively. Since the rod string and tubing alternatively stretch and recoil, the plunger stroke is less than the polished rod stroke. Then, stroke loss due to tubing deformation, λ_t (m), is expressed as follows:

$$\lambda_t = \frac{f_p \rho_l L_f g}{E} \cdot \frac{L}{f_t} \tag{1}$$

Where f_p and f_t are the cross-sectional areas of plunger and cross-sectional area of the tubing, respectively, m^2; L is pump depth, m; ρ_l is liquid density, kg/ m^3; E is the Young's modulus of the tubing (FRP tubing: 1.76×10^{10} Pa; steel tubing: 2.06×10^{11} Pa); and L_f is dynamic liquid level, m.

Meanwhile, stroke loss due to rod string deformation, λ_r (m), can be written as follows:

$$\lambda_r = \frac{f_p \rho_l L_f g}{E} \cdot \frac{L}{f_r} \tag{2}$$

Where f_r is the cross-sectional area of the sucker rod, m^2. Since ratio of the elastic modulus of the FRP tubing to that of the conventional steel tubing is found to be 0.09, λ_t will be greatly increased as the FRP tubing is stretched under the same fluid load. The pump efficiency due to stroke loss, η_λ, can be expressed as

$$\eta_\lambda = \frac{s - (\lambda_t + \lambda_r)}{s} \tag{3}$$

Where s is the polished rod stroke, m. Obviously, either an increase in stroke loss or a decrease of the polished rod stroke leads to a reduction in pump efficiency.

PARAMETRIC DESIGN

Materials

In general, wall thickness of the downhole FRP tubing is in a range of 7.7-10.2 mm, while its working pressure is from 16 to 20 MPa. The operating temperature for the anhydride and amine FRP tubing is found to be -30-80℃ and -30-110℃, respectively. In this study, a common anhydride FRP tubing (Xinda FRP Pipe Company, China) is used, whose physical parameters are tabulated in Table 1. Due to its extremely clean and smooth surface, roughness of the FRP tubing is in the range of 0.0015-0.0100 mm, while that of a new and an old seamless steel tubing is 0.0460 mm and 0.6000 mm, respectively. Accordingly, the corresponding friction factor for the FRP tubing is around 0.0095, which is only half of that of the aforementioned steel pipes. The friction factor between the FRP tubing and alloy metal 35CrMo is found to be 0.145, while that of N80 tubing and 35 CrMo is 0.213.

Anchor design

The rated tensile strength of the FRP tubing used in this study is 150.9 kN. The FRP tubing has a coiling structure of glass filaments

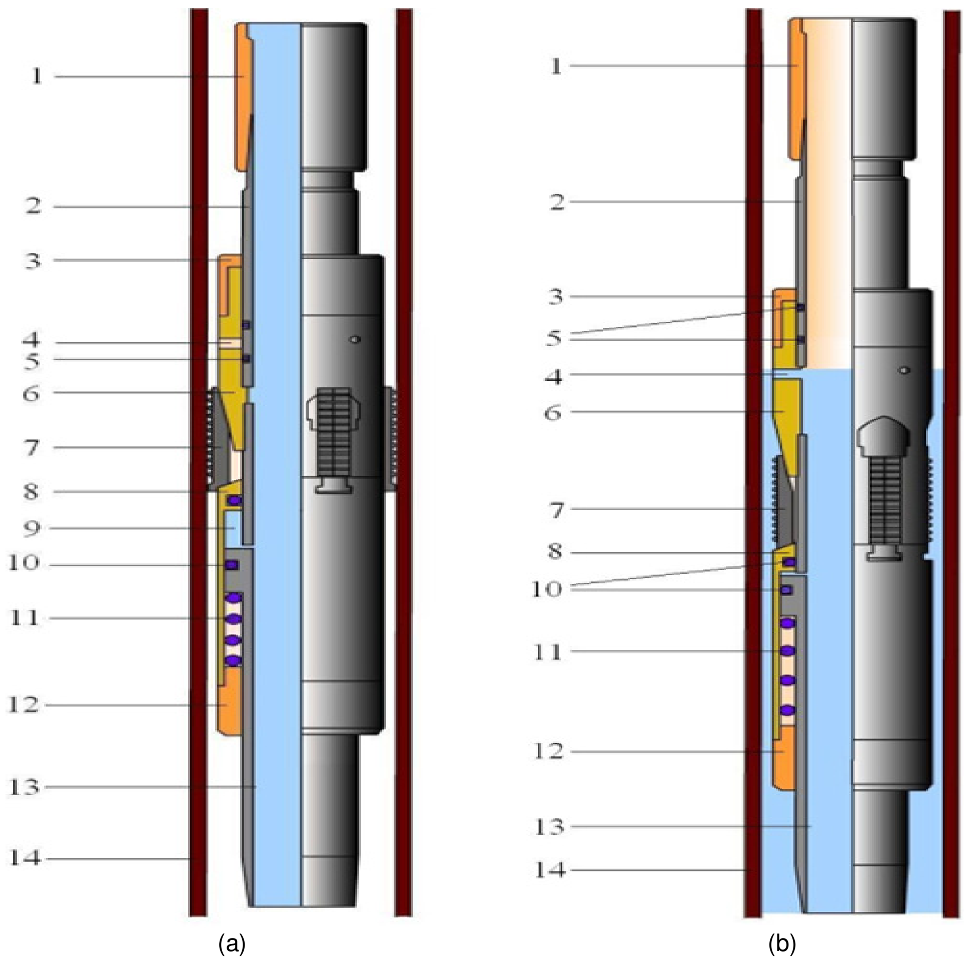


Figure 1. Schematic of a hydraulic anchor. at (a) Anchoring status and (b) Releasing status, 1-Upper joint; 2-Oil drainage nipple; 3-Upper protection cap; 4-Drain hole; 5-Seal ring; 6-Taper; 7-Slips; 8-Piston; 9-Hydraulic cavity; 10-Seal ring; 11-Spring; 12-Lower protection cap; 13-Centre tube; 14-Casing.

inside, which prevents it from withstanding a large axial stress. As such, a common tubing anchor set by compressive setting is not suitable for the FRP tubing. After several trial and errors, it is found that a hydraulic anchor is a better choice as it can be set and released by initiating a pressure difference. Figure 1 depicts schematic of a hydraulic anchor. In principle, fluid in the hydraulic cavity (Item #9) pushes a piston (Item #8) upward when the hydraulic pressure in the hydraulic anchor is higher than that in the annulus. Subsequently, the piston pushes the anchor slip (Item #7) upwards to increase the slip diameter via the guidance of a tapper (Item #6), which enables the anchor slip to anchor onto the casing (Item #14). To release the anchor, tubing is first to rotate clockwise to initiate an upward movement of the oil draining nipple, leading to switching on the draining hole (Item #4). In this way, fluids in the tubing anchor and the annulus have started communicating. The oil is then gradually drained out to balance the pressure inside and outside the anchor so that the piston will be repositioned under the action of a spring (Item #11). Naturally, the anchor slip will slide back as moving downwards along the taper (Item #6) to eventually release the anchor. Once the workover operation is completed, the pressure is the same inside and outside of tubing at a given depth. After the beam pumping is put into operation, pressure inside the tubing is increased up to 3 MPa higher than that of the annulus so as to set the anchor. A tubing anchor can be used to effectively prevent the tubing from extra stretching or recoiling while loading or unloading the fluids.

Tailpipe counterweight

The tubing string undergoes an upward buoyancy force while floating in the wellbore fluids. To ensure the FRP tubing always under the tensile stress, a piece of regular steel tubing can be added to the bottom of the FRP tubing as counterweight, or weighted tailpipe. The weighted tailpipe is designed in such a way that the whole tubing string should not only be under tensile stress with sufficient clearance, but also meet the requirement of the prorated strength. As plunger moves upwards on an upstroke, fluid load shifts to the plunger and the tubing string when the travelling valve is closed. The upward forces exerted on the tubing string mainly include liquid buoyancy, semi-dry friction between plunger

Table 2. The calculated buoyancy and tailpipe length for the FRP tubing.

Plunger depth (m)	Buoyancy (N)	Maximum tailpipe length (m)
800	18110	190
1000	22638	238
1200	27165	285
1400	31693	333
1600	36220	380

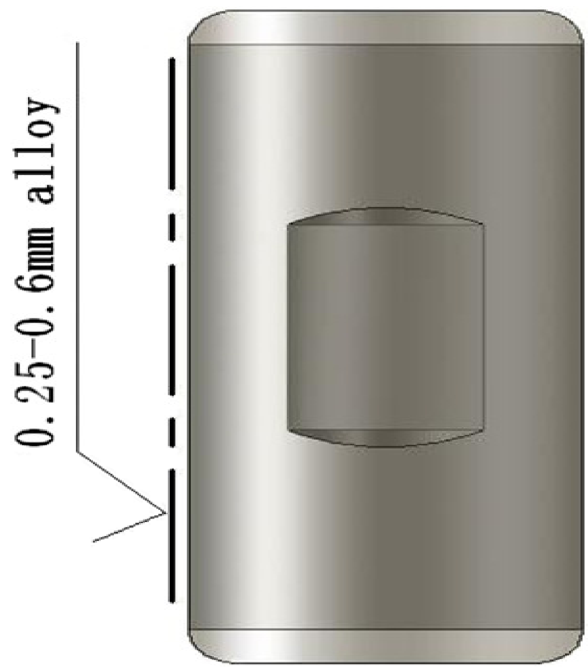


Figure 2. Coupling with circular arc and coating with alloy.

and pump barrel, friction when fluid flows through the standing valve, and friction of fluid to the tailpipe, among which the liquid buoyancy is found to be dominant, while the others can be neglected. If down hole tubings are the same, the buoyancy of liquid to tubing can be expressed as follows:

$$F_t = \rho_l g\left(L - L_f\right) f_t \tag{4}$$

In general, fluid density, ρ_l, can be assumed to be 1.0×10^3 kg/m^3; dynamic liquid level, L_f, can be either the static liquid level or the level of the killing fluid during workover. The buoyancy has its highest value when the dynamic fluid level reaches wellhead. The cross-sectional area of the FRP tubing, f_t, is calculated to be 2.31×10^{-3} m^2. The common 2 7/8-in (inner diameter: 62 mm) steel tubing is used as the tailpipe whose unit weight is 95 N/m. If the tailpipe counterweight is assumed to equal the buoyancy, the buoyancy exerted on tubing string and the maximum length of tailpipe can be calculated as a function of plunger depth, as shown in Table 2. The production tubular is composed of steel tailpipe, pump, tubing anchor, and the FRP tubing. Two more factors should be taken into consideration for designing a tailpipe counterweight. One is that pump and tubing anchor should have sufficient weight to assume partial function of the weighted tailpipe. The other is that an increase in wellbore temperature will impose a temperature effect on the FRP tubing.

Coupling and its coating

With alloy coating on the coupling surface, its surface roughness has been reduced to less than 1.6 μm, which leads to a smaller friction factor. Also, the ordinary chamfers of two sides of the coupling are modified into a circular arc to avoid the structure with a cutting edge (Figure 2). Since steel rod couplings are always making

Table 3. Comparison of production profile for Well L1-48.

Type of tubing	Pump diameter (mm)	Stroke length (m)	Pump speed (r/min)	Plunger depth (m)	Rod diameter (mm)	Dynamic liquid level (m)	Liquid production (t/d)	Water cut (%)	Total pump efficiency (%)
N80	44.5	2.93	4.6	1600.82	22.2	1154	17.6	95.0	58.4
FRP	44.5	2.87	2.7	1598.83	22.2	1127	3.9	97.6	22.4

Table 4. Component of pump efficiency for Well L1-48.

Type of tubing	Rod stretch (m)	Tubing stretch (m)	Stoke loss (m)	Pump efficiency due to stroke loss (%)	Pump efficiency due to other factors (%)	Total pump efficiency (%)
N80	0.36	0.11	0.47	83.6	69.9	58.4
FRP	0.35	0.67	1.02	64.3	34.9	22.4

contact with the inner wall of the FRP tubing, they can damage the inner surface if the coupling surface is very rough. It has been found that a common coupling has a surface roughness of 3.2 μm, which can damage the inner wall of FRP tubing. As such, the rod couplings associated with the FRP tubing have been modified in such a way that the coupling is coated with Ni-Cr-Si-B alloy to improve surface roughness and wear resistance.

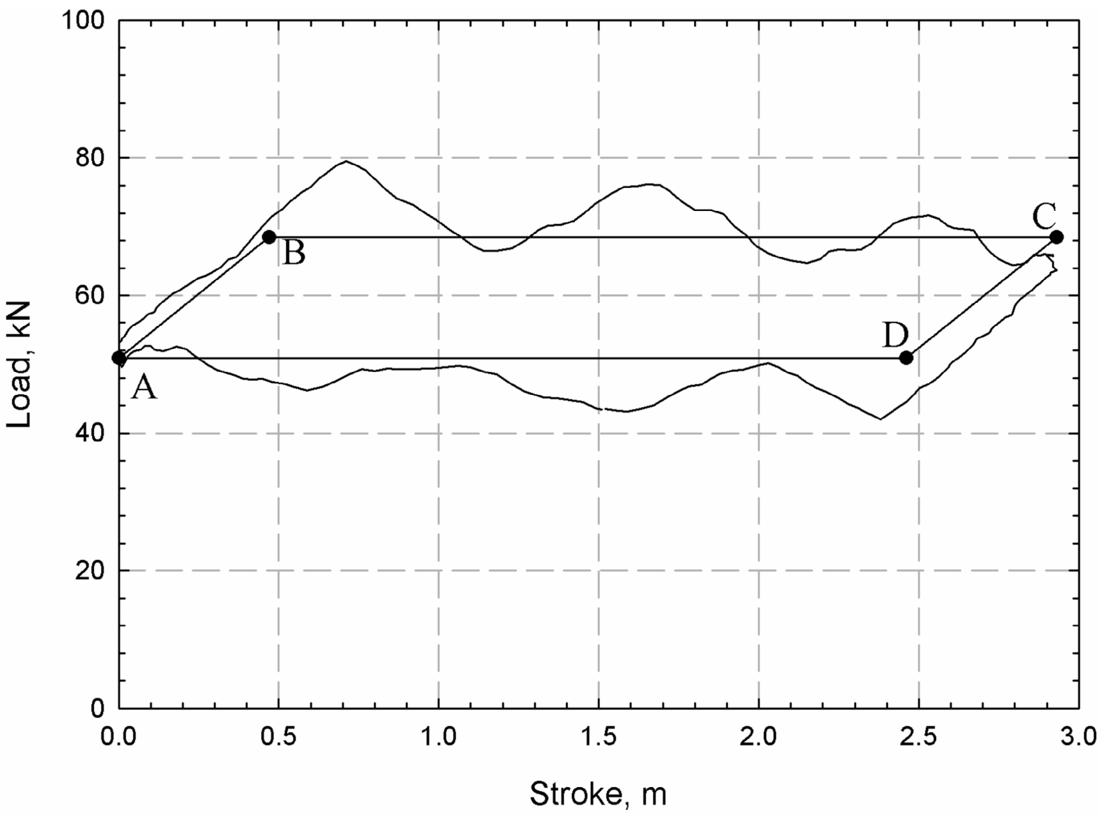
CASE STUDY

RFP tubing without anchoring

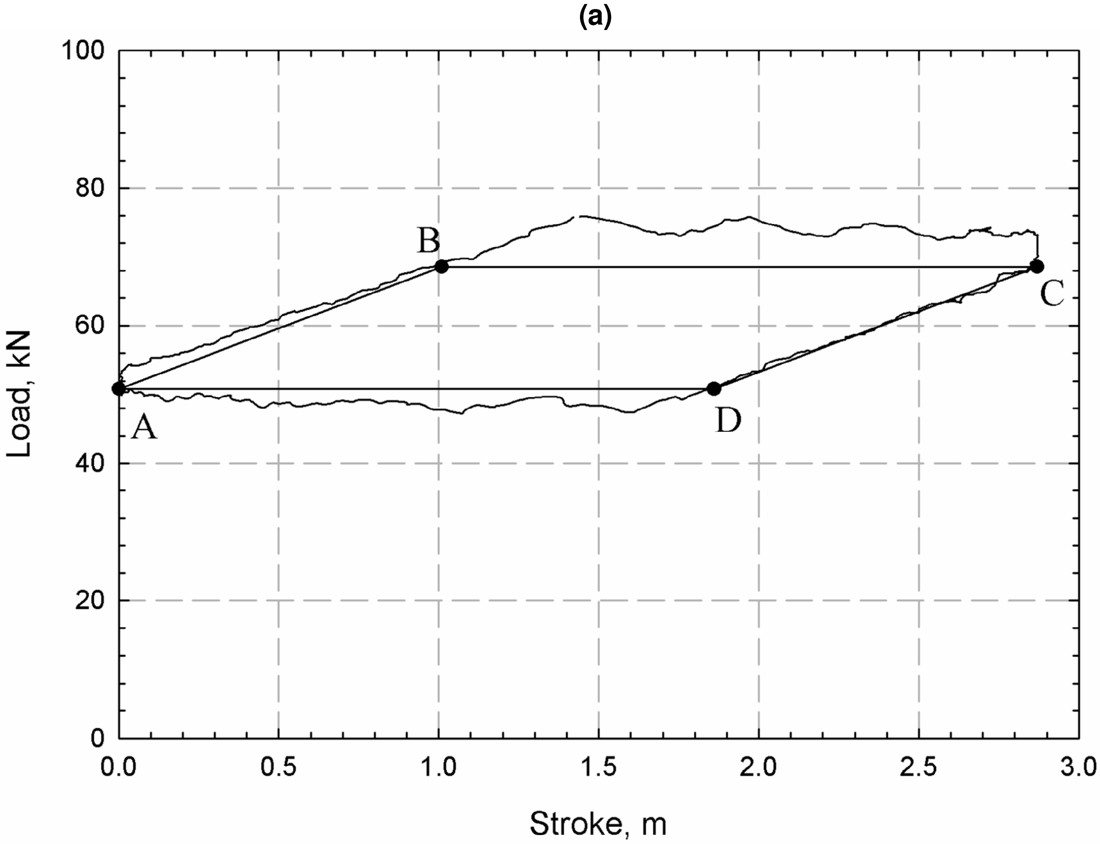
In June 2007, FRP tubing without anchoring was used to replace the conventional N80 tubing and firstly tested in Well L1-48 well. Table 3 compares its production profile before and after the test. It is worthwhile noting that coiled steel rod was used for both cases, except that a weighted tailpipe of 50 m was added to the FRP tubing. It is found that pump efficiency remains low with a value of 22.4% when FRP tubing is used without anchoring. Theoretically, factors affecting the pump efficiency mainly include stroke loss, gas liquid ratio, formation volume factor, clearance volume, and leakage. Except the tubing material and pump speed, other aforementioned factors (that is, gas liquid ratio, formation volume factor, clearance volume) can be isolated out for the performance analysis and comparison because they are very similar before and after the test. Since the FRP tubing has a smaller elastic modulus, a greater deformation under pressure is induced to result in a larger stroke loss for achieving lower pump efficiency (Table 4). Meanwhile, the FRP tubing string inherits a larger vibration during production because of a larger stretching and recoiling distance. Leaking on the FRP tubing may lead to a low production. In addition, the low pump efficiency may be ascribed to the fact that the alternating stress aggravates the damage of the tubing thread as the FRP tubing cannot withstand a high compressive stress. Figures 3a and b are the dynamometer cards of well L1-48 before and after test, respectively, where the parallelogram is the ideal one. The stroke loss by using the steel tubing is calculated to be 0.47 m, while that of the FRP tubing is 1.02 m. As mentioned previously, since the FRP tubing have an elastic modulus of 0.09 times over that of the steel tubing, the FRP tubing has a larger stretching and recoiling distance under hydraulic fluid column, leading to a higher stroke loss.

FRP tubing with anchoring

As observed previously, it is necessary to anchor the FRP tubing for not only reducing vibration, but also maintaining stable tensile stress during the alternatively liquid loading and unloading. Meanwhile, adding a heavy weighted tailpipe to the bottom of pump allows us to keep the FRP tubing under tensile stress continuously, leading to stable forces that exert on the tubing as well as reduction of the vibration. The proposed technique has been successfully applied to more than ten wells. For illustration purpose, the production profiles of five wells (that is, GLL38X113, DXX6X77, GLL38X113, DXY88-5 and Well DXY37-3) are tabulated in Table 5. As can be seen from Table 5, the pump efficiency is in the range of 50.8 to 90.9% with an average value of 74.5%. This means that adopting tubing anchor and weighted tailpipe impose a positive impact on the pump efficiency. In addition, compression of the FRP tubing during production has been avoided to mitigate effect of the alternating stress imposed on the tubular, and thus extends its operational life. For wells with unsuccessful



(a)



(b)

Figure 3. Dynamometer card of Well L1-48 without anchoring for (a) N80 tubing and (b) FRP tubing.

Table 5. Production profiles for the FRP tubing wells with anchoring.

Well	Tailpipe length (m)	Pump diameter (mm)	Stroke length (m)	Pump speed (1/min)	Pump depth (m)	Dynamic liquid level (m)	Liquid production rate (t/d)	Pump efficiency (%)
GLL38X113	300	57.2	4.8	2.0	1100	936	32.3	90.9
DXX6X77	270	44.5	3.0	4.0	1600	1058	21.6	80.3
GLL38X113	300	57.2	4.8	2.0	1100	892	30.8	86.7
DXY88-5	300	57.2	3.0	2.0	1100	732	14.2	63.9
DXY37-3	350	57.2	3.0	2.5	1400	384	14.1	50.8

application of the FRP tubing is resulted from the coupling dropout due to its weak thread. This implies that significant improvement should be made to enhance the threads on the FRP tubing prior to its extensive application (Zhao, 2010). With visual observation on the FRP tubings taken out from the five test wells, minor eccentric wear has been identified on the inner walls and coupling outside surface with no corrosion and scale.

Conclusions

A pragmatic and efficient technique has been developed to perform parametric design of the downhole FRP tubing with successful applications in beam pumping wells. As for wells equipped with FRP tubing, hydraulic tubing anchor can be used to minimize its stretch and recoil together with its vibration, while steel tailpipe should be used as a counterweight to reduce the axial compression. The proposed theoretical formulations are sufficient to determine the tailpipe counterweight. It has been found from five test wells that such parametric design significantly mitigates eccentric wear between the rod string and the tubing together with tubing corrosion and that average pump efficiency of test wells has also been greatly increased up to 74.5%.

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REFERENCES

Arian GH (1996). Physical and chemical performances of fiberglass tubulars in super critical application of CO_2. Paper SPE 36280, presented at Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, United Arab Emirates, October 13-16.

Cowley TW, Hatfield DA (2004). A case history of FRP pipe as an economical alternative to carbon steel pipe. Paper NACE 04606, presented at the Corrosion Conference and Exhibition, New Orleans, LA, March 28-April 1.

Eric C, Edward D, William E (1998). Polyethylene lined tubing in rod pumped wells. Paper SPE 39815, presented at SPE Permian Basin Oil and Gas Recovery, Midland, TX, March 25-27.

Gauchel JV (1985). Mechanical performance of fiberglass laminates for sucker rod applications. Paper SPE 14691, presented at SPE Production Technology Symposium, Lubbock, TX, November 11-12.

Hall SC (1999). Abrasion resistance of linings in filament wound composite pipe. Paper NACE 99053, presented at the Corrosion Conference and Exhibition, San Antonio, TX, April 25-30.

Hicks AW (1986). Using fiberglass sucker rods in deep wells. Paper SPE 14974, presented at SPE Deep Drilling and Production Symposium, Amarillo, TX, April 6-8.

Peralta D, Maggioni A, Garcia R, Martin D (2006). Successful application of glass reinforced epoxy (GRE) casing in hydraulically fractured water injection wells. Paper SPE 102144, presented at SPE Annual Technical Conference and Exhibition, San Antonio, TX, September 24-27.

Philip E (2003). Manual tubing rotation reduces rod pumping failures by 76%. Paper SPE 80886, presented at SPE Production and Operations Symposium, Oklahoma, OK, March 22-25.

Romera G, Robles J, Peacock H, Morris W, Peralta D (2008). Glass reinforced epoxy casing: lessons learned after cementing and completion of 70 wells. Paper SPE 116020, presented at SPE Annual Technical Conference and Exhibition, Denver, CO, September 21-24.

Ryan RA (1988). Controlling rod body corrosion failures with spray-metal plastic-coated sucker rods. Paper SPE 17299, presented at Permian Basin Oil and Gas Recovery Conference, Midland, TX, March 10-11.

Scott PJB, Al-Hashem A, Carew A (2007). Experiments on MIC of steel and FRP downhole tubulars in west Kuwait brines. Paper NACE 07113, presented at the Corrosion Conference and Exhibition, Nashville, TN, March 11-15.

Siegmund AJ (1997). Metal alloys: corrosion protection for the future. Paper NACE 97073, presented at the Corrosion Conference and Exhibition, New Orleans, LA, March 9-14.

Stringfellow WD (1987). Make-up of fiberglass tubulars. Paper SPE 17272, presented at SPE Production Technology Symposium, Lubbock, TX, November 16-17.

Wang HW, Zhao L, Yang F, Zhao H, Huang XM, Wang WZ (2008). Study on HDPE Lined Tubing in Rod Pumped Wells. J. Oil Field Equip., 37(2): 74-77.

Williams JG (1987). Oil industry experiences with fiberglass components. Paper OTC 5380, presented at Offshore Technology Conference, Houston, TX, April 27-30.

Zhang Q (2000). Principle and design of oil production engineering. China University of Petroleum Press, Dongying, China.

Zhao MC (2010). Issues and improvement on fiberglass-reinforced plastic tubing in beam pumping wells. China Pet. Mach., 38(3): 82-84.