Journal of Software Engineering

ISSN 1819-4311

Academic
Journals Inc.

www.academicjournals.com

Journal of Software Engineering 7 (3): 106-113, 2013
ISSN 1819-4311 / DOI: 10.3923/jse.2013.106.113

Experimental Study on the Growth of Diameter for Coiled Tubing under Different Internal Pressure

Xiaoqiu Li, Jianchun Fan, Lei Fan, Jun Lei and Yujiang Sun
College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing, Beijing, 102249, China

Corresponding Author: Jianchun Fan, College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing, Beijing, 102249, China

ABSTRACT

It was well known that CT (Coiled tubing) worked under severely plastic deformation and was used widely in the oil field with its special advantage. Under the interaction of bending, axial loads and internal pressure, especially over 20 MPa the growth of diameter was quick and the deformation of the pipe was serious which would lead to the incompatibility failure, or the accidents resulting from the mechanism declining. So the study on the sectional deformation of the pipe during severely plastic deformation was very important for the safety operation. In this study, the full-scale fatigue experiment was subjected on the fatigue machine of CT under different internal pressure and the testing experiment of diameter was carried on. The variation and distribution of the growth of the diameter to CT along the bending board were discussed which would provide reliable basis for judging the dangerous place and the stress concentration area. The laws of the growth ratio of the maximum diameter during the fatigue deformation were found which could evaluate the degree of the deformation. And the real-time monitoring of diameter could predict the remaining life.

Key words: Growth ratio of diameter, low cycle fatigue, full-scale, severely plastic deformation, coiled tubing

INTRODUCTION

CT was originated from PLUTO operation (shortened by Pipe Line under the Ocean in the plan of the Second World War). The CT technology had much advantage in the application in the oil field. It was used widely in exploration and development of oil and gas, drilling, completion, work over (Gao and Xiao, 2012; Zhang and Shi, 2010). But as the core component, CT was wrapped on the reel. When it passed through the goose neck arch guide with a certain curvature, it was bent, then straightening by the injection to downhole. It would be caused the notable geometrical shape deformation applied by the periodic complicated loads (Song *et al.*, 2008; Han *et al.*, 2000). In one operation cycle it would have six times deformation (three times for straightening-bending deformation, three times for bending-straightening deformation) which was in the plastic deformation state all the time (Brown *et al.*, 1997; Radovan and Steven, 2000; Brown, 1994; Wu *et al.*, 2000). And the four times had the relationship with the goose neck arc guide. The "bending-straightening" fatigue was its main deformation forms. More than 20 MPa was the high pressure by the regulation of the oil field. If it worked under the high pressure, its ratio and amplitude of the growth of diameter was bigger. The growth of diameter caused the increasing of circumference and ovality. The change of the sizes could lead to incompatibilities with other equipments. Contrasting with the perfect round pipe, the growth of diameter could greatly decrease the anti-collapse property of CT. The bigger growth of diameter deformation could affect the seal, equipment clamping and the anti-collapse property. The growth ratio of diameter was different loaded by different internal pressure. So real-time monitoring of the CT diameter is necessary to locate mechanical damage and judge the degree of deformation.

At present, the study on the growth mode of diameter is seldom. Tipson (1998) analyzed the growth of diameter and elongation mechanism using classical multiracial plastic theory and the fatigue experiment (Tipton and Brown, 1994; Tipton and Newburn, 1992; Tipton,1995). Newman established the diametral growth mode based the experiment, but the thickness was not considered (Newman *et al.*, 1991; Newman, 1991). Yang (1999) established the diametral growth model based on the test data and used 3-D surface curve fitting to predict the CT increasing of the average diameter under the different pressure (Yang and Gao, 1999). But the coefficients is too many and uncertainty. And 10% as the maximum allowable growth was more than 6% of the regulation of the oil field. Lei *et al.* (2011) studied on the relationship between internal pressure and the sizes of the pipe, but the real-time variation of diameter was not analyzed. In this study, based on the formers' results, the full-scale fatigue "bending-straightening" experiment under different pressure and the cyclic complicated loads and the real-time variation of diameters of the sample were investigated on the fatigue machine of CT. The sectional deformation was studied during cyclic bending. Namely, the variation of diameter and the growth laws of the maximum diameter were studied and the relationship between the remaining life and the maximum diameter was analyzed which could predict diametral growth, judge the dangerous place and the degree of deformation before severe damage occurred.

MATERIALS AND METHODS

Experimental equipment: Based on the work principle of CT, using Cantilever beam the fatigue machine of CT was designed. Because CT was the fatigue damage of bending-straightening correlating to the goose neck arch. The sizes of bending board were the same as the goose neck arc guide. The fatigue machine was shown as Fig. 1. The sample was sealed on both ends and the internal pressure was pumped into the sample. One end was limited by clamp and the other was moved under the head. The maximum journey which was the displacement that moved from the straightening board to the bending board. And the maximum displacement was set by three

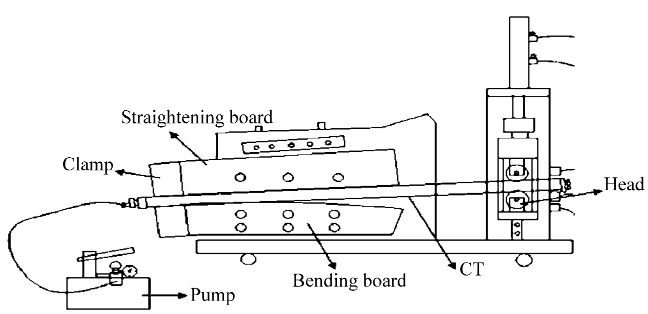

Fig. 1: Fatigue machine of CT

sensors. The first moving direction was downward. When CT reached the position which was the maximum displacement, the counter recorded one cycle. Every 100 cycles, the sample was taken off the machine and the sizes were measured and analyzed until fracture.

Experiment condition and the sample mechanism: The type of the material was CT 80 steel, used widely in many operations of oil industry. The yield strength was 482.3 MPa, the tensile strength was 551.2 MPa, the elongation was 30% and the hardiness (HRC) was 22. The loading frequency of the fatigue-testing machine was 2.5 S/T. The internal pressure was filled with 5, 10, 15, 20, 25, 30 and 35 MPa, respectively which could be controlled by the pump. The media was water. The maximum load was 10t. In this study the change and distribution of diameter under the high pressure (20, 25, 30 and 35 MPa) were dominant analyzed in real-time.

Measurement scheme: The measurement scheme is followed as Fig. 2. The full-scale fatigue experiment was established. The sizes of the sample were followed: the outer diameter was 38.1 mm, the wall thickness was 3.2 mm and the length of the sample was 2000 mm. Z was the down direction and the maximum displacement was 300 mm. The internal pressure was pumped into the pipe with 20, 25, 30 and 35 MPa, respectively. The 14 key points was chosen on the surface of the sample. The sizes at every key point was measured and calculated. Based on the experiment analysis the maximum diameter occurred in the direction of AC and the minimum one occurred in the direction of BD. By measuring diameters of the each point in the different directions, the growth ratio of diameter was calculated.

The surface of the pipe was divided into 4 equal sections. The 4 generatrices that paralleled the axis were gained A, B, C, D. Fourteen key points to be measured on the different axis and the distance between the adjacent two points was 20 mm. About 4 points on every key point's section are on the 4 generatrices, such as from I-I, point 1 has 4 directional points 1A-D. So the diameters were measured on the two different directions AC and BD at every key point. The growth ratio of diameter was calculated based on the different directional diameters at each key point.

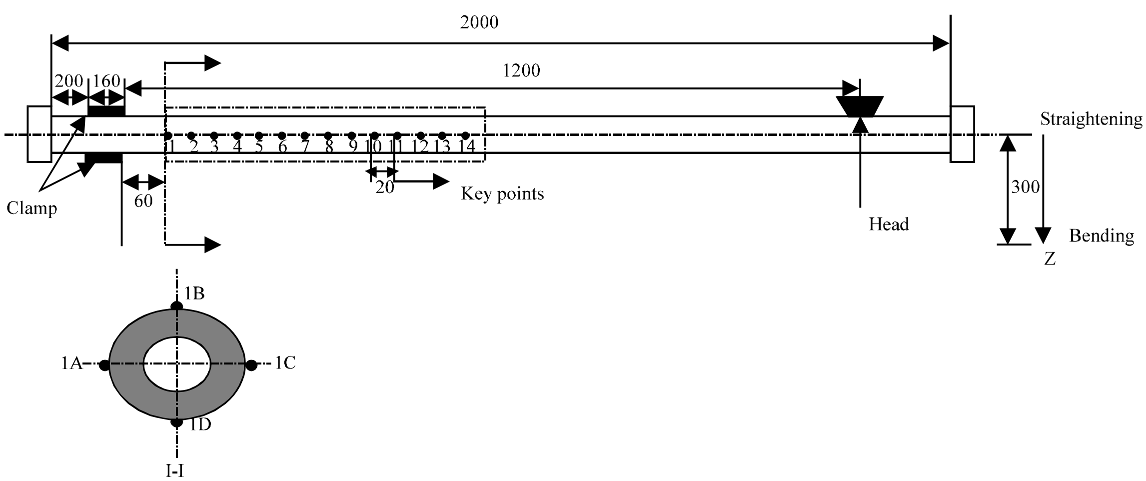

Fig. 2: Schematic diagram of key points and the loads

RESULT AND ANALYSIS

Diameter variation at every point under different internal pressure: The GRD (shortened by growth ratio of diameter) could describe the degree of deformation. The equation was Eq. 1:

$$GRD = \frac{D_{imax} - D_0}{D_0} \quad (1)$$

D_{imax} was the maximum of the diameter of every 100 cycles. D_0 was the initial diameter. The variation relationship of diameter of CT under different pressure was shown as Fig. 3.

According to the growth ratio of diameter under 5, 10, 15, 20, 25, 30 and 35 MPa pressure, the growth ratio of diameter was higher with the internal pressure increasing. Usually the maximum allowable growth of diameter was 6%. But less than 20 MPa, the growth ratios of diameter all were not over 6% after CT cyclic bending fatigue failure which was about 2%. But over 20 MPa, the deformation of the pipe was very distinct. When the pressure reached 30 and 35 MPa, before failure, the growth ratios of diameter were all over 6%. The biggest growth ratio got to 8.6089% which was farther more than the limitation of size to work reliably. The GRD at different direction both increased. The GRD at AC was bigger obviously than that at BD direction. So the maximum diameter occurred at AC direction which was most importantly studied. In this study, the real-time variation of GRD over 20 MPa was focus on study. In the oil field, CT always worked in the maximum allowable pressure was 35 MPa. Therefore, the change laws of GRD were analyzed under 20, 25, 30 and 35 MPa at Fig. 4.

It was shown from Fig. 4 that the growth of diameter increased with the cycle increasing. The amplitude of diameter after fracture was much than that at the initial stage. When the cycle increased, the growth of diameter at different point firstly increased to the maximum then decreased. And the fracture occurred at the place where the growth ratio of diameter reached the maximum. Loaded by 20 MPa at the area from point 4-8, the change of diameter was the most over 2% and this area was the dangerous where the deformation was the most. Forced by 25 MPa, the dangerous deformation area consists of area from point 2-8. When the pressure reached 30 MPa, the dangerous deformation area made up from point 1-10. But when the pressure got to 35 Mpa, the dangerous deformation area was the range from point 1-11. So when the cycle increases the maximum sectional deformation area increased and the degree, the amplitude of the deformation

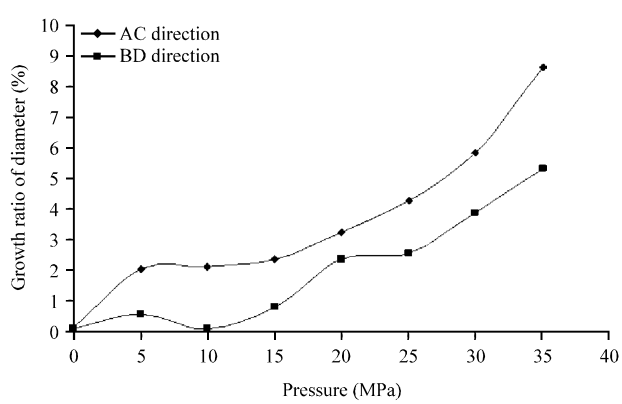

Fig. 3: Relationship curve of GRD at different direction under different pressure

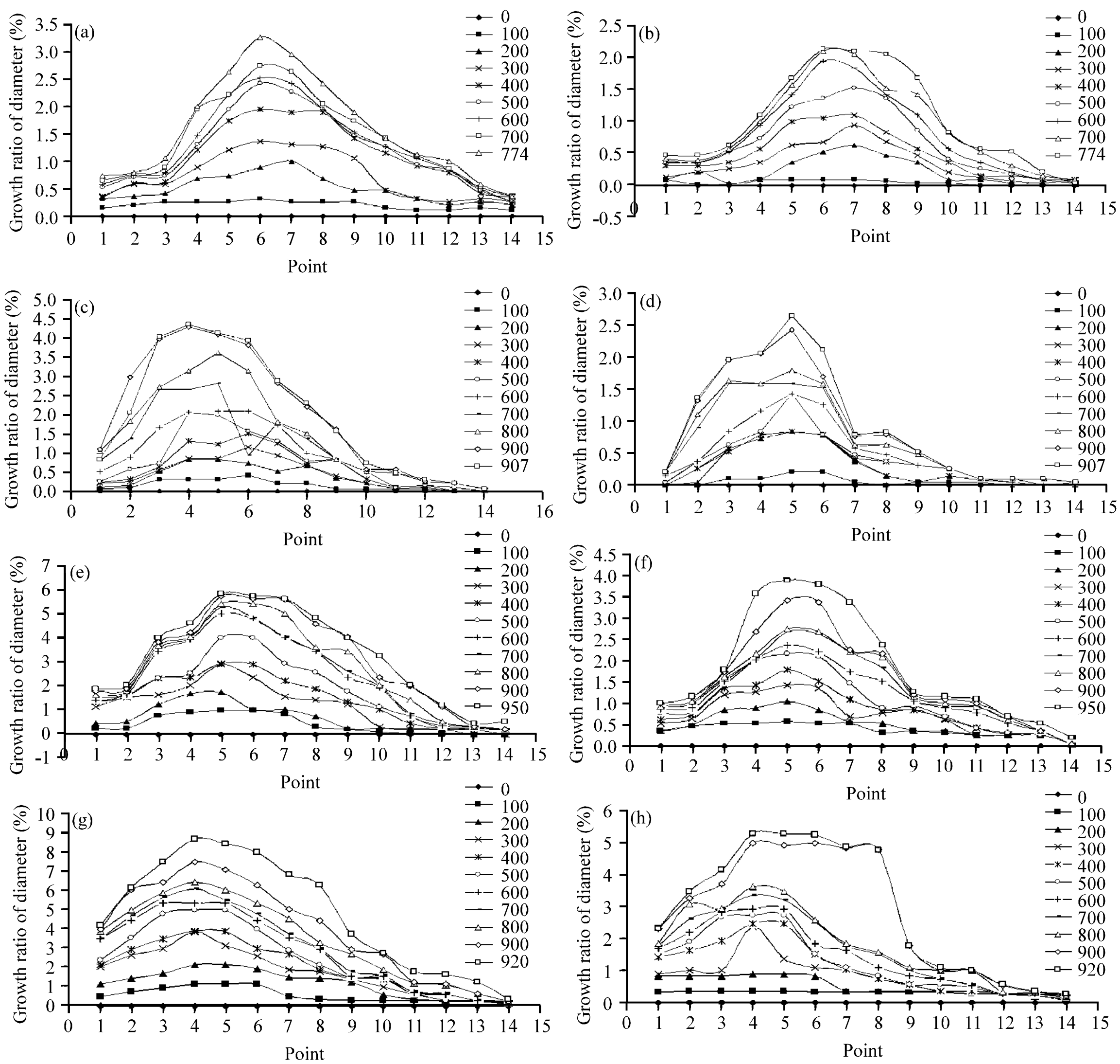

Fig. 4(a-h): Variation of GRD at (a) AC direction under 20 MPa at different cycles, (b) BD direction under 20 MPa at different cycles, (c) AC direction under 25 MPa at different cycles, (d) BD direction under 25 MPa at different cycles, (e) AC direction under 30 MPa at different cycles, (f) BD direction under 30 MPa at different cycles, (g) AC direction under 35 MPa at different cycles and (h) BD direction under 35 MPa at different cycles

increased. And the fracture damage always occurred at the dangerous deformation area under the different pressure. So it was necessary to ensure the place of mechanism damage and grasp the variation law of diameter under different pressure.

Result and analyses of laws of maximum diametral growth ratio under different internal pressure: The curve-fitting and the relationship between maximum diameter growth ratio and the cycles under different internal pressure were shown as Fig. 5. Figure 5a for 20 MPa, Fig. 5b for 25 MPa, Fig. 5c for 30 MPa, Fig. 5d for 35 MPa.

It was showed that when the cycle increased, diameter grew approximately nonlinearly. The maximum diameter growth ratio reached 3.2021% for 20 MPa, 4.6194% for 25 MPa, 5.9% for

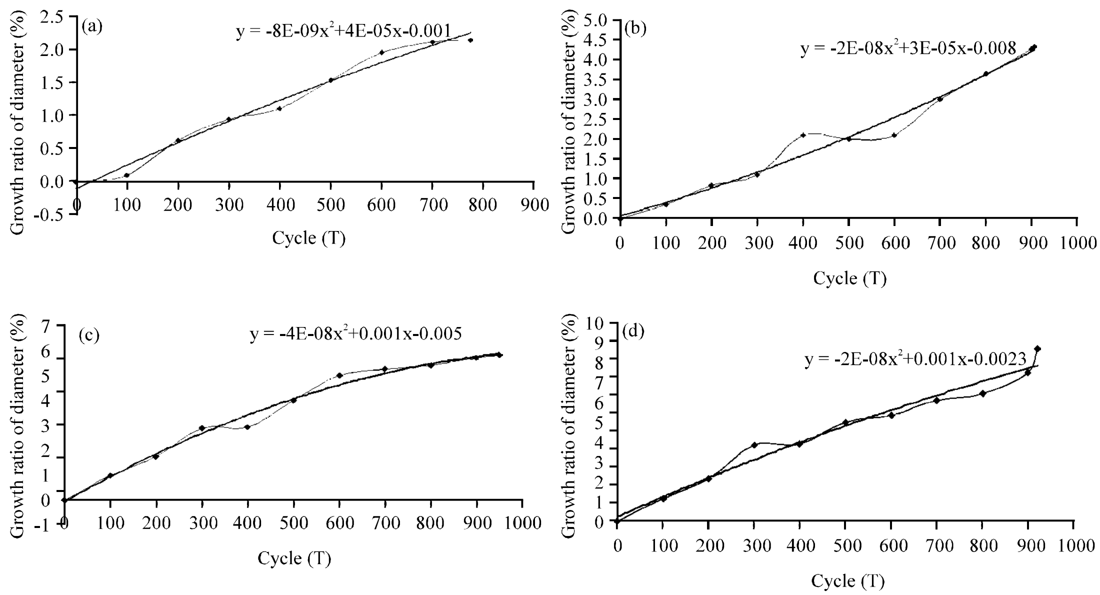

Fig. 5(a-d): The curve-fitting and the relationship between the maximum diametral growth ratio and (a) Cycles under 20 MPa, (b) Cycles under 25 MPa, (c) Cycles under 30 MPa and (d) Cycles under 35 MPa

30 MPa, 8.6089% for 35 MPa after fracture. When the internal pressure was higher, the amplitude and the growth ratio of diameter were more quickly. The relationships between GRD and the cycle under different internal pressure were shown as curve-fitting Eq. 2-5. Equation 2 for 20 MPa, Eq. 3 for 25 MPa, Eq. 4 for 30 MPa and Eq. 5 for 35 MPa:

$$y = -8\times10^{-9}x^2+4\times10^{-5}x-0.001 \tag{2}$$

$$y = -2\times10^{-8}x^2+3\times10^{-5}x-0.008 \tag{3}$$

$$y = -4\times10^{-8}x^2+0.001x-0.005 \tag{4}$$

$$y = -2\times10^{-8}x^2+0.001x-0.0023 \tag{5}$$

The increasing of hoop stress and the bending strain leaded to the growth of the diameter. So the law of the growth of diameter could reflect the stress concentration. According to the law of GRD and the curve-fitting, the real-time monitoring diameter size under different pressure would judge the deformation degree. Before fracture, if the growth ratio of diameter was more than the allowable limit of the growth of diameter before fracture, operator can judge the remaining life and eliminate unnecessary factors facilitating growth.

CONCLUSION

The laws of the growth of diameter can be obtained by the full-scale fatigue and the deformation of sectional sizes experiments. The variation laws of growth of diameter and the GRD of maximum diameter can help the operators detect early diametral growth before serious damage appeared. The affective measurement can be taken to avoid the accident according to monitoring dangerous place and the variation law of GRD. So the diameter can be one of standards to judge remaining life of CT. But the condition in the oil field is very complicated; some factors affect the remaining life has not been considered, such as large displacement, erosion and so on. The change of diameter can cause the variation of circumference and the ovality which can affect the remaining life of CT. There is still much work to do for evaluating degree of damage. Further work will focus on studying the relationship between cyclic loads and the laws of sectional sizes.

ACKNOWLEDGMENT

This research has been supported by the support plan of National science and technology under Grant No. 2008BAB37B04 .We also thank the anonymous reviewers for their insightful and valuable hints.

REFERENCES

Brown, P.A., 1994. Use of fatigue test machine to investigate coiled tubing diameter growth. Proceedings of the 2nd International Conference and Exhibition on Coiled Tubing, March 28-31, 1994, Houston, Texas.

Brown, P.A. J.L. Dickerson and CTES, 1997. Development and use of an analytical model to predict coiled tubing diameter growth. Proceedings of the SPE/ICoTA North American Coiled Tubing Roundtable Conference, April 1-3, 1997, Montgomery, Texas.

Gao, X. and G. Xiao, 2012. Analysis on low cycle fatigue of coiled tubing. Welded Pipe Tube, 35: 32-36.

Han, X., H. Kang and X. Li, 2000. Method and apparatus for constant magnetic inspection of ellipticity of coiled tubing. Petroleum Mach., 28: 17-19.

Lei, L., P. Wang and Z. Shen, 2011. An experimental study of the coiled tubing under the effect of internal pressure and cyclic bending. China Petroleum Machinery, 39: 5-12.

Newman, K.R., 1991. Coiled tubing pressure and tension limits. Proceedings of the Offshore Europe Conference, September 3-6, Society of Petroleum Engineers, UK.

Newman, K.R., D.A. Newburn and D. Schlumberger, 1991. Coiled-tubing-life modeling. Proceedings of the SPE Annual Technical Conference and Exhibition, October 6-9, Society of Petroleum Engineers Inc., Dallas, Texas.

Radovan, R. and M.T. Steven, 2000. Multiaxial cyclic ratcheting in coiled tubing-part II experimental program and model evaluation. J. Eng. Mater. Technol., 129: 166-167.

Song, Y., Y. Wang and X. Gao, 2008. Development of fatigue life test equipment and full-size test for coiled tubing. Sci. Technol. Rev., 26: 66-71.

Tipson, S.M., 1998. Coiled tubing deformation mechanics: Diametral growth and elongation. SPE Prod. Facilities, 13: 194-199.

Tipton, S.M. and D.A. Newburn, 1992. Plasticity and fatigue damage modeling of severely loaded tubing. Proceedings of the Advances in Fatigue Lifetime Predictive Techniques, April 24, 1990, San Francisco, California, USA., pp: 369-382.

Tipton, S.M. and P.A. Brown, 1994. Monitoring coiled tubing fatigue life. Proceedings of the 2nd International Conference on Coiled Tubing Operations, March 29-31, 1994, Houston, Texas.

Tipton, S.M., 1995. Multiaxial plasticity and fatigue life prediction in coiled tubing. Fatigue Lifetime Predict. Tech., 3: 283-304.

Wu, Y., X. Wu and H. Kang, 2000. Approach and instrument of constant magnetic measurement for diameter of coiled tubing. Automat. Instrument., 15: 7-10.

Yang, Y.S., 1999. Understanding Factors Affecting Coiled-Tubing Engineering Limits. Society of Petroleum Engineers, Gillette, Wyoming.

Yang, Y.S. and C. Gao, 1999. Development of a coiled tubing diametral growth model. Proceedings of the SPE Rocky Mountain Regional Meeting, May 15-18, 1999, Society of Petroleum Engineers, Gillette, Wyoming, pp: 333-336.

Zhang, Y. and K. Shi, 2010. Application and Development of Coiled Tubing. West China Exploration Engineering Pub., China.