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Effective Application of Solid Expandable Tubular During the Enhancement of Heavy Oil Recovery in China, Lessons Learned and Experience Shared

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Abstract

As the traditional thermal recovery became less effective in exploring the heavy oil reservoirs, some newly developed techniques such as chemical flooding, SAGD and HDCS are demonstrating their advantage in the recovery process in China. However, the ever increasingly used new techniques often compromised severely the well integrity as the flow of extremely high temperature fluid or gas caused quick damage to casing, leaving the wellbore less reliable. This compromise requires urgently a workover strategy that would maximize the well's life span and guarantee the effectiveness of new techniques. Solid expandable tubular (SET) was field-proven in casing patching activities, but its application in the heavy oil recovery has not been attempted due to severe temperature challenge. We made innovations on the traditional structure of SET and got valuable results. The tubular after expansion was integrated with the original casing as a whole and the rubber was removed in-between, the wellbore size was maintained utmost and the casing was further strengthened. Meanwhile the expansion cone was put outside the tubular which is a big step forward in SET structure.

Indoors experiments demonstrated sound performance of the new structure in the simulative temperature of 350℃, the plan for the field application was optimized based on the lessons collected in this experiment. High temperature well applications by SET were carried out in Liaohe oilfield which is famous for its heavy oil resource in China, and the detailed process as well as the outcome were compared and analyzed, finally the conclusions were drawn as a result of the whole study. We expect our work will help expand this enabling technology to better facilitate the enhancement of heavy oil recovery and maintain solid well integrity during the heavy oil production.

Key words: Solid expandable tubular; Heavy oil recovery; China

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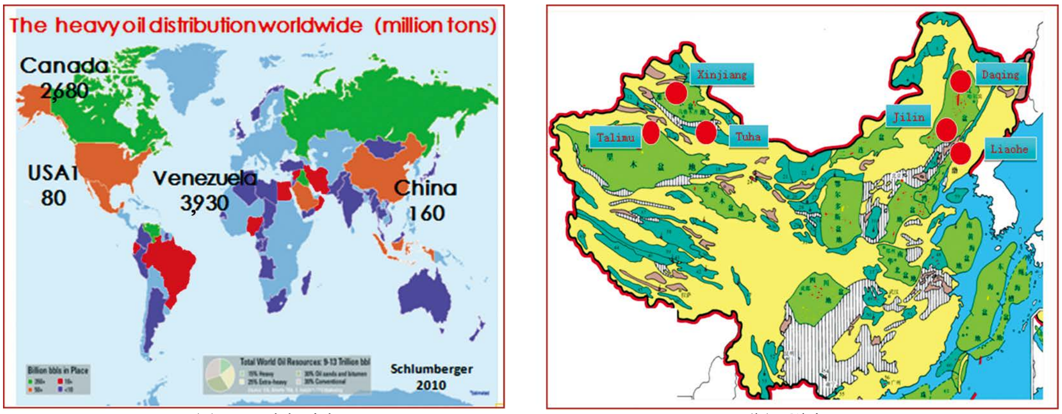
INTRODUCTION

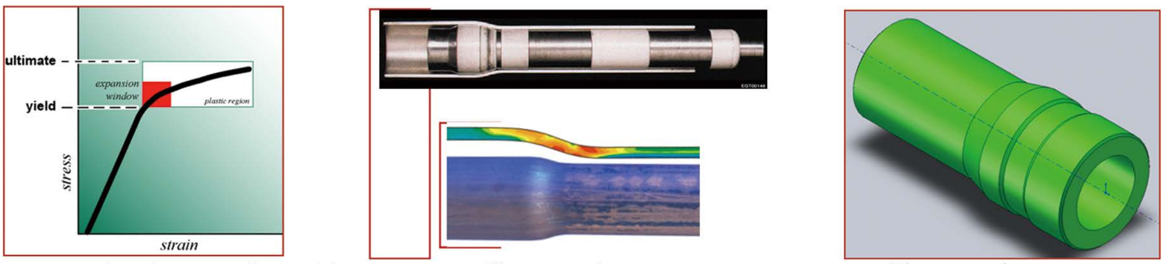
Heavy oil resources are mainly concentrated in the USA, Canada, Venezuela and China, the distribution is shown in Figure 1. The predicted reserves of heavy oil in China are over 8 × 10 tonnes, which could be found in the Songliao, Bohai Bay and Junggar basins. The production of heavy oil has increased year by year in China, accounting for 10% of total output annually. So far techniques such as chemical flooding, SAGD and HDCS are demonstrating their advantage in the recovery process, contributing to the majority production of heavy oil. However, the ever increasingly adopted new techniques often compromised severely the well integrity as the flow of extremely high temperature fluid or gas caused quick damage to casing, leaving the wellbore less reliable. Take the Liaohe oilfield for example,the temperature in the wellbore is over 200℃ after steam huff and puff operation, one important reason for the huge number of damaged cased well, the conventional methods such as casing replacement or reshaping, were inadequate in terms of cost and technical capability[1-3].



(a) Worldwide (b) China

Figure 1
The Distribution of Heavy Oil in Worldwide and China

Extrusion is a significant manufacturing process which is used in the production of a wide range of products since last century. Solid expandable tubular (SET) is also a kind of extrusion, it is a down-hole process consisting of expanding the diameter of the tubular by pulling or pushing a mandrel through it, the principle could be seen in Figure 2. Right now solid expandable tubular has been field-proven in casing patching activities, thousands of wells in China had been operated with this technology and yielded lucrative results, but its application in the heavy oil recovery has not been attempted due to severe temperature challenge. In this paper, we explored the mechanism of heating effect on the casing and made innovations on the traditional structure of SET, field test was performed in the well operated with steam huff and puff, the most valuable conclusion is this technology could be used in the wellbore environment over 350℃. The technical detail would be shared later.



The stress and strain curve of material The expansion process The expansion cone

Figure 2
The Principle of Solid Expandable Tubular

1. PROBLEM DESCRIPTION

Steam injection is an important way of heavy oil production in China, as the temperature goes up and down repeatedly; the residual stress will appear inside the casing and lead to its failure. The following described the axial thermal stress of casing during the operation of steam hull and puff according to the thermal theory.

(a) When the stress increase is within the compressive yield strength of casing during the temperature rise

$$\sigma_s = -\frac{\alpha_c E_c \Delta T}{1-\mu_c} + \frac{2\mu_c E_c C_{c1}}{(1+\mu_c)(1-2\mu_c)}$$

σ_s: The axial stress of casing; α_c: Linear expansion coefficient of casing; E_c: Elastic modulus; ΔT: The temperature change; μ_c: Poisson ratio; C_{c1}: Thermal capacity of casing.

Under this condition, there is no residual stress in the casing.

(b) When the stress increase is exceeding the compressive yield strength of casing during the temperature rise

$$\sigma 1_s = -\sigma_s - \frac{\alpha_c E1_c \Delta T}{1-\mu_c} + \frac{2\mu_c E1_c C_{c1}}{(1+\mu_c)(1-2\mu_c)}$$

$\sigma 1_s$ and $E1_c$ represented the axial stress and elastic modulus at this stage respectively, the residual stress will appear and if the temperature is even higher, the casing will be damaged by the compressive residual stress.

(c) When the stress increase is within the tensile yield strength of casing during the temperature drop

$$\sigma 2_s = -\sigma 1_s - \frac{\alpha_c E2_c \Delta T}{1-\mu_c} + \frac{2\mu_c E2_c C_{c1}}{(1+\mu_c)(1-2\mu_c)}$$

$\sigma 2_s$ and $E2_c$ represented the axial stress and elastic modulus at this stage respectively.

(d) When the stress increase is exceeding the tensile yield strength of casing during the temperature drop

$$\sigma 3_s = \sigma_s - \frac{\alpha_c E3_c \Delta T}{1-\mu_c} + \frac{2\mu_c E3_c C_{c1}}{(1+\mu_c)(1-2\mu_c)}$$

As the temperature of casing dropped to its initial state, is the residual stress during the fisr cycle of steam injection, the casing will be damaged if the stress is higher than the casing's strength. Based on the formula above, we could deduce the stress and strain of casing after many cycles of steam injection as below.

$$\Delta\varepsilon = \frac{1}{\gamma}\log\frac{(\frac{C}{\gamma})^2 - (\sigma_{\min} + k)^2}{(\frac{C}{\gamma})^2 - (\sigma_{\max} + k)^2}$$

Δε is the accumulated strain of casing after operation with repeated steam huff and puff, C, k, γ are the characteristic coffcient of the material which could be obtained by looking into the manual.

$$\Delta\sigma = 2[k + \frac{C}{\gamma}\text{th}(\gamma\frac{\Delta\varepsilon}{2})]$$

Δσ is the accumulated stress of casing.

As has been discussed above, to ensure the wellbore integrity in the high temperature environment is a big challenge during the enhancement of heavy oil production, more specifically how to protect or repaire the casing. So far, SET has played an important role in casing patching; its working principle could be found below. Generally the whole operation consists of three parts, first the tubular is delivered into the position to patch the damaged casing through the tubing, the damaged part is marked by a circle in the picture, second water is pumped into the tubular and forms a force to push the mandrel to move upword, as the tubular is expanded, the rubber upon it is also experiencing the same amount of expansion and stuck to the casing afterward, sealing off the leaking point or the damaged part of casing, thirld the tool is employed to remove the plug to ensure the free flow of the wellbore, the process is shown in Figure 3.

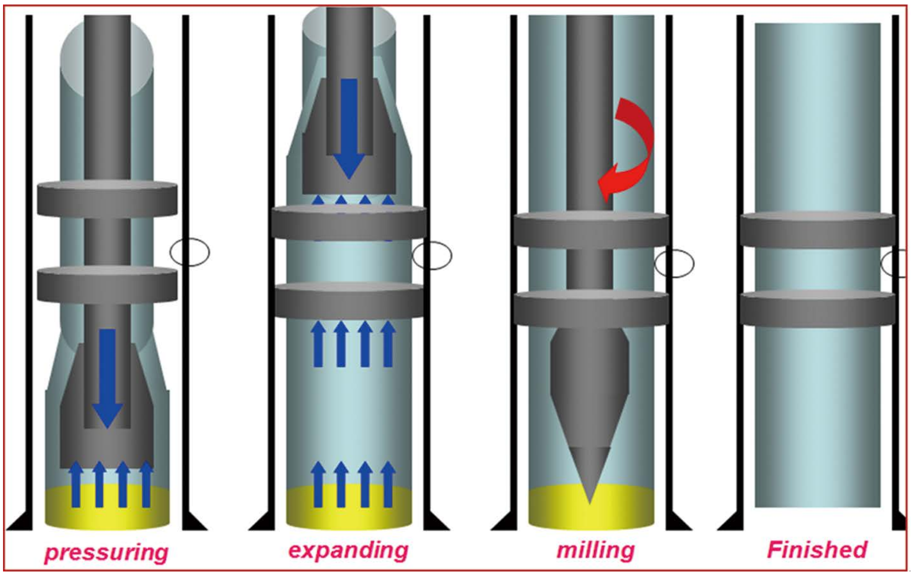


Figure 3
The Casing Patching Process by SET

This technology has been trialed in the oilfield numerous times and contributed to protect the integrity of casing, but the structure is vulnerable to high temperature; therefore SET has not been applied in the heavy oil production well.

2. INNOVATIVE STRUCTURE DESIGN OF SET

The structure of SET is shown in Figure 4, the expansion tool was put inside the tubular and ready to be pushed upward either by hydraulic or mechanical means, or even the combination of both, usually rubber was used to seal the annular space between the casing and the tubular, this structure has great advantages in the field application and is used widely across the world. However there was one significant weakness on no account be ignored, the sealing component, rubber, is vulnerable to the temperature over 120℃, making it almost impossible in patching the casing in the high temperature well condition.

Considering the scenario mentioned above, the new design was invented as shown in Figure 5.

The expansion tool is put outside the tubular and powered by a set of cylinder and piston device, an anchor is used to fix the tubular during the expansion process Figure 6(a), as SET was delivered into position, liquid was pumped into the tubing to activate the piston, due to the function of the anchor, the expansion tool could expand the tubular and the expanded part was stuck to the casing, sealing the annular space Figure 6(b). After the initial expansion, the tubular was fixed to the casing and the anchor lost its function, then the same operation could be repeated until the end of the expansion process Figure 6(d).

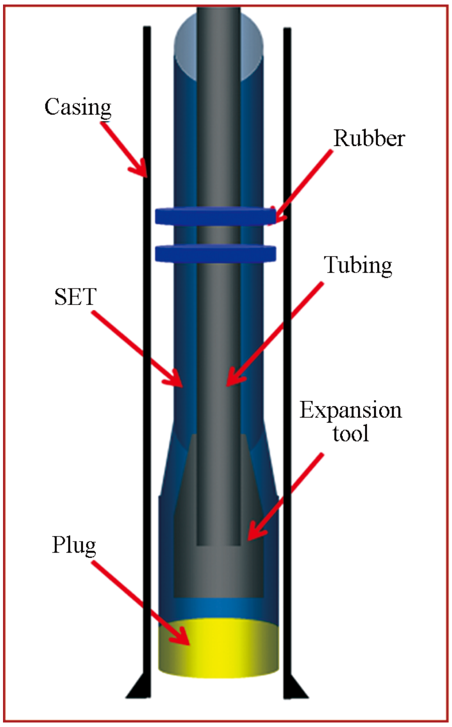


Figure 4
The Conventional Structure of SET

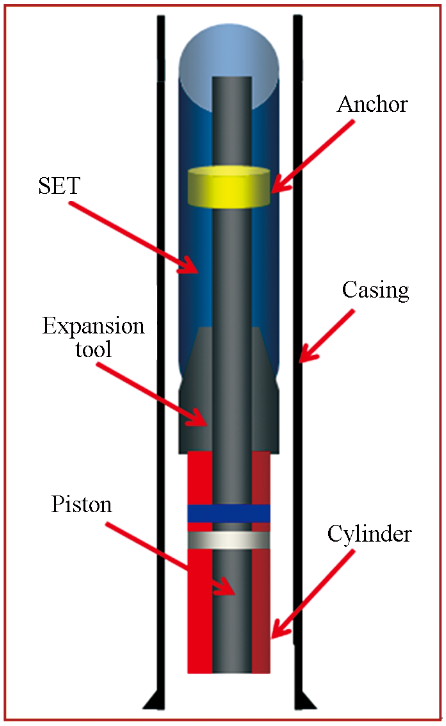


Figure 5
The New Design

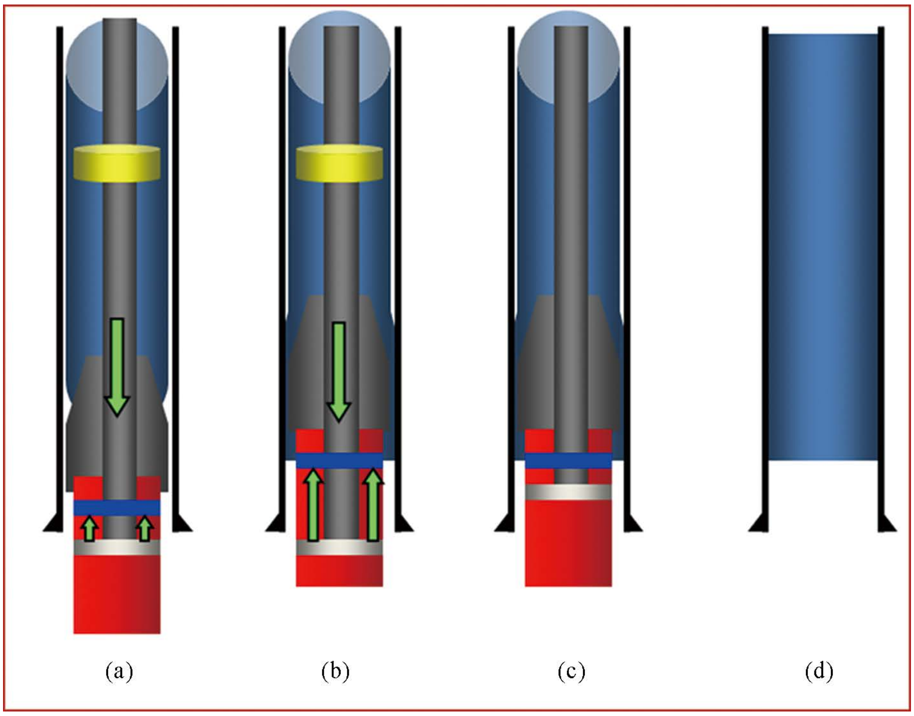


Figure 6
Working Principle of the New Design

Compared to the traditional one; the advantages of this structure could be summarized as below:

(1) Without the restriction of launcher, the expansion ratio can be further increased;

(2) The whole set of the patching tool provides larger wellbore size;

(3) The expansion process is more reliable without worrying the breakdown of the launcher part which was weak in strength due to the relatively thin wall thickness;

(4) The new structure adopted metal to metal sealing method, reinforcing the casing in terms of strength and thermal reistance directly.

3. EXPERIMENTAL TEST

The full-scale experiment was performed to test the reliability and security of the new structure, each tubular, 114D × 7 t in standard dimension, was manufactured by the cold-drawing pipe forming process. The expansion tool was 42 CrMo in material with a hardness of about HRC 45 - 50; its maximum OD was 108 mm in order to achieve the expansion ratio of 8%.

Some key components such as piston, cylinder and anchor were shown in Figure 7. A total of three steps were taken to finish the whole experiment.

(a) The test of the piston-cylinder system;

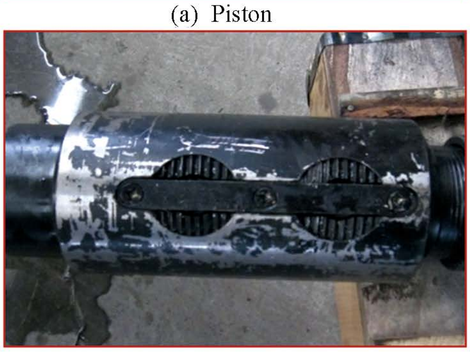
(b) Expansion experiment;

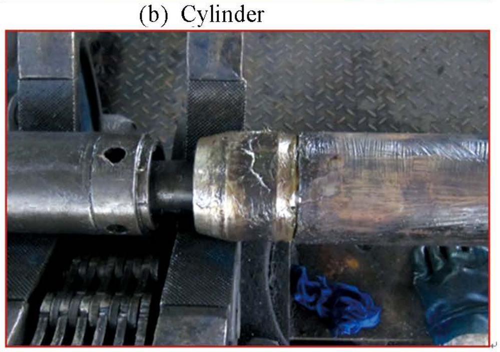
(c) The test of the sealing ability of th tubular in the high temperature environment.

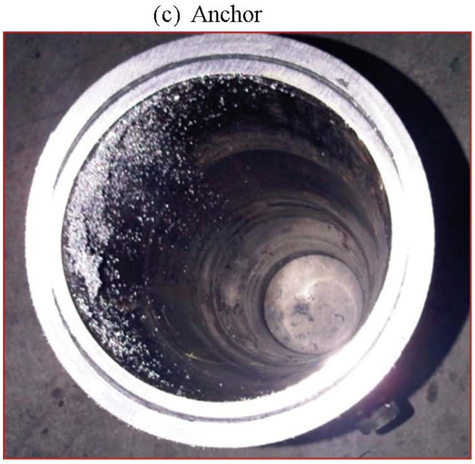
The results demonstrated that the powering system was reliable without any leak under 30 MPa pressure, the expansion experiment was carried out smoothly with the maximized expansion pressure less than 15 MPa and the anchor played its role well, the 8% expansion ratio guaranteed more than 8 t suspending force between the casing and the tubular given the total contact length 1 m.


(a) Piston


(b) Cylinder


(c) Anchor


(d) Assembly


(e) Casing and post expanded tubular

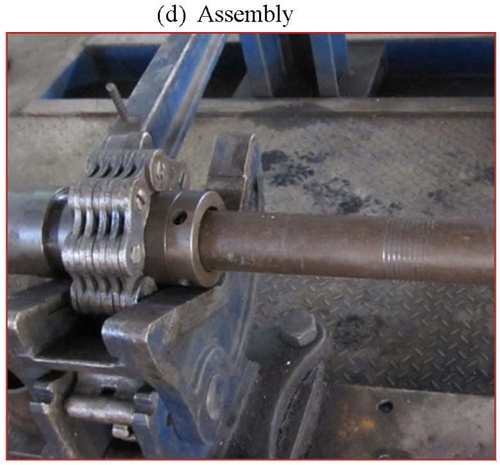

(f) Test of suspending force

Figure 7
Indoors Experiment

Figure 8
High Temperature Test of SET

The post expanded tubular and the casing was heated up to 350℃ to simulate the well operated with steam huff and puff, then the sealing ability of the tubular and the casing was tested as shown in fig, there was no leak between during 20 MPa test. This process was repeated 3 times and the results were sound and stable.

4. FIELD APPLICATION

The field test was carried out in Liaohe oilfield where the steam huff and puff was performed most frequently and the casing was also damaged seriously due to the thermal stress. The conventional SET was by nomeans an option, therefore the newly designed structure was considered. The following was some parameters recorded during the first field test.

So far, this technology had been applied in the high temperature wells more than 20 times, all the operations were successful, according to the feedback, 5 wells in the Shuguang oil plant which were installed with SET had survived the steam huff and puff operation 5 times without any problem in 2011, a total of about 6,000 t heavy oil was produced.

Table 1
The Parameters of the SET During the Field Operation

SET (mm)	Casing (mm)	ID of SET after expansion (mm)	Expansion pressure (MPa)	Integrity force (kN)	Sealing ability (MPa)
114 × 5	139.7 × 7.72	114	14 - 19	≥ 650	≥ 15

Figure 9
Field Test in the Liaohe Oilfield

CONCLUSION

In this paper, the effect of steam huff and puff on the casing was explored, the most effective casing patching tool, SET, was redesigned to adapt to the high temperature environment, experiments were carried out to testify this approach and some valuable conclusions were obtained.

The operation of steam huff and puff will lead to the birth of thermal stress in the casing, as the operation is repeated, the accumuled stress will definitely cause the damage of casing, making the wellbore less reliable, this issue has been common in the heavy oil production zone in China.

Traditional caing patching tool, SET, was restructured to remove the component sensitive to the high temperature, and the post expanded tubular was integrated with the casing as a whole, reinforcing the casing in terms of strength and thermal stress resistance.

So far this technology has been applied in the heavy oil production well, contributing to the integrity of wellbore and enhancement of heavy oil production in China.

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