Mechanics performance test and feasibility analysis to replace the rigid sucker rod for 6K T300

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Abstract. A experiment plan was designed according to the working conditions of sucker rod and the requirements for pump depth in 3000 m in the oil field, the tensile strength for 6K T300 under a normal temperature and high temperature was measured by using universal testing machine, and then, the resistance to corrosion for a crude oil was verified by measuring the tensile strength for 6K T300 after crude oil immersion at a certain time, and the conclusions are that the material is sensitive relatively to corrosion of crude oil and that the tensile strength of the 6K T300 compared with similar products is lower, a proposal to the GH company that to meet the need of oil field production instead of the rigid rod the tensile strength and corrosion resistant for a crude of the T300 6 k materials have to do further efforts was pointed out.

1. Introduction

More than 90% of oil pumping wells are mechanical oil pumping in the world petroleum industry today, and over 80% of mechanical oil pumping wells are sucker-rod pumping wells [1]. Sucker rod can be divided into three grades which are C, D and K according to the API [2]. Grade C sucker rods is mainly applied to light load, middle load and weak corrosion oil wells, which is mainly carbon steel or chrome alloy steel, the tension strength is 794~965 MPa. Grade D sucker rods is mainly applied to middle load, heavy load and sour oil wells, which is mainly carbon steel or manganese steel, such as series of Gr-Mo, the tension strength is 620~794 MPa. Meanwhile, Grade K sucker rods is mainly applied to light load, middle load, low sulfur and medium corrosion oil wells at normal temperature, which is mainly nickel-molybdenum alloy steel, such as series of Ni-C-Mo or Ni-Cr, the tension strength is 588~794 MPa.

Performance of traditional rigid rod has many deficiencies. For example: high cost, heavy, easy corroding, pumping with higher energy consumption, difficult to install and maintain, etc. However, the carbon fibers have the advantage of high strength, lightweight, fatigue tolerance, abrasion resisting, and corrosion resistance and so on. The carbon fibers steady of rigid rod have been studied by the western literature in the age of twenty century ninetieth. The result is that carbon fiber composite is a new material which can solve the problem of oil exploitation of high water cut oil wells, deep well, ultra-deep well and corrosive wells [3-7]. Our domestic scholars made the same conclusion quite independently.

literature [8] points out that the coiled flexible rod of carbon fibers has higher specific strength and
specific modulus, higher fatigue strength, better wear resistance and higher corrosion resistance than common or fiber reinforced plastics rod, while it has good heat resistance, and it is more convenient to oil exploitation, the daily fluid production rate raised by over 30%, electricity consumption were visibly reduced and its working life were considerably extended. The domestic research on flexible continuous sucker rod of carbon fibers and the application of oil field in North China, Qinghai, Central Plains and Sheng Li have been described in the literature [9], it is pointed out that the flexible continuous sucker rod improved the pump efficiency greatly, saved lots of energy and reduces consumption. It is also concluded that using flexible continuous sucker rod is the development trends in future. Zhang [10] and co-workers studied phenolic resin-based carbon fiber as materials of flexible continuous sucker rod, indicating that it could replace the traditional rigid rod. These studies suggest that it is possible to replace rigid rod by using carbon fibers.

However, most of the above investigations were based on the imported carbon fibers; no study was carried out on domestic ones, this really renders the development and application of domestic carbon fibers. Herein, mechanical properties of 6K T300 (produced by GH Company) are tested; it is focused on the study of using carbon fibers based flexible continuous sucker rod to replace rigid rod. According to the measurements of tensile strength as well as oil corrosion resistance under low and high temperature, the carbon fibers based flexible continuous sucker rod (produced by GH Company) can replace traditional rigid rods.

2. The experiment plan design
The experiment aims are to verify the feasibility of using 6K T300 materials in the underground oil field pumping environment, and thus verify the mechanical properties which related to the underground pipeline pumping oil according to the environmental conditions.

2.1. Working condition of pumping-oil
- When the oil pumping rod of beam pumping unit works, if the beam swings upward, it will be driven the plunger rod of piston pump and oil to complete the pumping action – this is upstroke; if the beam swings down, the plunger rod of piston pump will move down according to its own weight – this is down stroke (empty return trip). Thus, the oil pumping rod must have sufficient tensile strength to withstand the load suspension point when pumping.
- The temperature will increase 3°C when the oil well depth increase 100 m [1], if the pump setting depth at 3000 m, the temperature of oil and water mixture will be close to 100°C, therefore, the high temperature performance of 6K T300 must be verified.
- The composition of the crude oil is complex, including the various mineralization, paraffin, acid, alkali, water and other ingredients, and even organic ingredients. The working conditions are very poor, it is needed to verify the corrosion resistance of carbon fiber in crude medium, and also tensile strength in corrosive conditions.

2.2. Experiment scheme design
According to the conditions (1), the tensile strength of 6K T300 will be tested, then compared to that of traditional oil pumping rod to verify its feasibility.

According to the conditions (2), the temperature is 100°C when the pump setting depth at 3000 m, the tensile strength of 6K T300 at different conditions (from room temperature to 100°C) will be measured to verify its high temperature properties.

According to the conditions (3), the 6K T300 materials will be soaked in crude oil for different time (from 3 to 360 days), then tensile strength of this materials will be tested to verify its corrosion resistant for the crude oil condition.

2.3. Laboratory equipment
Laboratory equipment: AG-IS-10 kN universal testing machine.
Force measurement precision: ±0.5%.
Sampling rate: 1.25 m/sec.
Test speed range: 0.005–1000 mm/min.

3. The experimental results

3.1. Test the tensile strength for 6K T300 at the room temperature
Production material of 6K T300 by GH company, mono filament d = 7 μm, a bunch of tensile diameter (6 k): $D = \sqrt{6000 \times 10d^2} = 542$ μm, that is, D=0.542 mm. Use 1 kN universal testing machine to measure room temperature tensile strength for the 6K T300, the data can be seen in table 1.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa | Break elongation /% |
|-----|------------------------|---------------------|-----------------------|--------------------------|---------------------|
| 1   | 0.542                  | 100                 | 567                   | 383                      | 17%                 |
| 2   |                       | 110                 | 548                   | 381                      | 17%                 |
| 3   |                       | 57                  | 537                   | 372                      | 16%                 |
| 4   |                       | 90                  | 583                   | 408                      | 18%                 |
| 5   |                       | 71                  | 544                   | 383                      | 21%                 |
| 6   |                       | 55                  | 523                   | 358                      | 20%                 |
| 7   |                       | 77                  | 541                   | 365                      | 15%                 |
| 8   |                       | 78                  | 530                   | 361                      | 25%                 |
| 9   |                       | 82                  | 562                   | 388                      | 20%                 |
| 10  |                       | 71                  | 521                   | 348                      | 17%                 |
| Average | 0.542                | 79                  | 525                   | 345                      | 21%                 |

According to the standard, 6 K tensile strength index should be 3.5 GPa for T300 material under the room temperature, apparently the material strength is low.

3.2. For 6K T300 tensile strength test at different temperature
For less than 100°C, use the heat water, heat preservation material in the container. By controlling the water temperature set temperature the material respectively measure tensile strength at 40°C, 60°C, 80°C, 98°C temperature, the results are shown in table 2-5.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa | Break elongation /% |
|-----|------------------------|---------------------|-----------------------|--------------------------|---------------------|
| 1   | 0.542                  | 135                 | 427                   | 205                      | 0.14                |
| 2   |                       | 155                 | 694                   | 227                      | 0.083               |
| 3   |                       | 145                 | 339                   | 211                      | 0.2                 |
| 4   |                       | 145                 | 1057                  | 245                      | 0.08                |
| 5   |                       | 140                 | 920                   | 230                      | 0.114               |
| Average | 0.542                | 144                 | 687                   | 224                      | 0.12                |
Table 3. At 60°C material tensile strength.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa | Break elongation /% |
|-----|------------------------|---------------------|-----------------------|---------------------------|---------------------|
| 1   | 0.542                  | 190                 | 886                   | 282                       | 0.05                |
| 2   | 1.40                   | 723                 |                       | 247                       | 0.12                |
| 3   | 1.35                   | 510                 |                       | 240                       | 0.13                |
| 4   | 1.40                   | 1437                |                       | 294                       | 0.05                |
| 5   | 1.40                   | 431                 |                       | 216                       | 0.07                |
| Average | 0.542              | 149                 | 781                   | 256                       | 0.08                |

Table 4. At 80°C material tensile strength.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa | Break elongation /% |
|-----|------------------------|---------------------|-----------------------|---------------------------|---------------------|
| 1   | 0.542                  | 180                 | 418                   | 231                       | 0.08                |
| 2   | 1.60                   | 445                 |                       | 227                       | 0.1                 |
| 3   | 1.45                   | 626                 |                       | 363                       | 0.09                |
| 4   | 1.50                   | 439                 |                       | 259                       | 0.08                |
| 5   | 1.55                   | 565                 |                       | 313                       | 0.08                |
| Average | 0.542              | 158                 | 499                   | 279                       | 0.08                |

Table 5. At 98°C material tensile strength.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa | Break elongation /% |
|-----|------------------------|---------------------|-----------------------|---------------------------|---------------------|
| 1   | 0.542                  | 155                 | 255                   | 209                       | 0.16                |
| 2   | 1.60                   | 310                 |                       | 227                       | 0.15                |
| 3   | 1.55                   | 310                 |                       | 221                       | 0.18                |
| 4   | 1.60                   | 339                 |                       | 220                       | 0.18                |
| 5   | 1.55                   | 439                 |                       | 210                       | 0.17                |
| Average | 0.542              | 157                 | 331                   | 217                       | 0.17                |

Results analysis: tensile strength of 6 k T300 around 60°C is the highest, the tensile strength declined slightly at 60°C~98°C, but the reduction is not big, the average tensile strength of still keep 331 MPa until to 98°C, explain the T300 6 k material of high temperature stability is good.

3.3. Oil corrosion resistance experiment
To soak T300 6 k materials in crude oil medium for 3 days, 5 days, 10 days, 30 days, 60 days and 180 days, each time period sampling 5 groups, tensile test, respectively. The results are shown in table 6-11.
### Table 6. The tensile strength on corrosion for 3 days.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa |
|-----|------------------------|---------------------|-----------------------|--------------------------|
| 1   | 0.542                  | 155                 | 189                   | 165                      |
| 2   |                        | 80                  | 157                   | 129                      |
| 3   |                        | 100                 | 200                   | 173                      |
| 4   |                        | 100                 | 201                   | 174                      |
| 5   |                        | 80                  | 191                   | 168                      |
|     | Average                | 0.542               | 103                   | 187                      | 162                      |

### Table 7. The tensile strength on corrosion for 5 days.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa |
|-----|------------------------|---------------------|-----------------------|--------------------------|
| 1   | 0.542                  | 50                  | 158                   | 46                       |
| 2   |                        | 70                  | 139                   | 124                      |
| 3   |                        | 100                 | 96                    | 41                       |
| 4   |                        | 50                  | 91                    | 53                       |
| 5   |                        | 80                  | 119                   | 70                       |
|     | Average                | 0.542               | 80                    | 121                      | 67                       |

### Table 8. The tensile strength on corrosion for 10 days.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa |
|-----|------------------------|---------------------|-----------------------|--------------------------|
| 1   | 0.542                  | 100                 | 86                    | 57                       |
| 2   |                        | 70                  | 97                    | 88                       |
| 3   |                        | 70                  | 78                    | 52                       |
| 4   |                        | 80                  | 82                    | 68                       |
| 5   |                        | 60                  | 96                    | 75                       |
|     | Average                | 1.715               | 76                    | 88                       | 68                       |

### Table 9. The tensile strength on corrosion for 30 days.

| No. | Diameter of sample /mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa |
|-----|------------------------|---------------------|-----------------------|--------------------------|
| 1   | 0.542                  | 90                  | 81                    | 53                       |
| 2   |                        | 70                  | 87                    | 79                       |
| 3   |                        | 70                  | 71                    | 53                       |
| 4   |                        | 80                  | 78                    | 62                       |
| 5   |                        | 60                  | 86                    | 75                       |
|     | Average                | 0.542               | 74                    | 80.6                     | 64.4                     |
Table 10. The tensile strength on corrosion for 60 days.

| No. | Diameter of sample mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa |
|-----|-----------------------|---------------------|-----------------------|--------------------------|
| 1   | 0.542                 | 80                  | 76                    | 52                       |
| 2   |                       | 70                  | 83                    | 75                       |
| 3   |                       | 70                  | 78                    | 55                       |
| 4   |                       | 80                  | 79                    | 61                       |
| 5   |                       | 60                  | 81                    | 72                       |
| Average | 0.542              | 72                  | 79.6                  | 63                       |

Table 11. The tensile strength on corrosion for 180 days.

| No. | Diameter of sample mm | Original length /mm | Tensile strength /MPa | Lower yield strength /MPa |
|-----|-----------------------|---------------------|-----------------------|--------------------------|
| 1   | 0.542                 | 70                  | 78                    | 53                       |
| 2   |                       | 70                  | 76                    | 65                       |
| 3   |                       | 70                  | 79                    | 62                       |
| 4   |                       | 80                  | 69                    | 61                       |
| 5   |                       | 60                  | 81                    | 70                       |
| Average | 0.542              | 72                  | 76.6                  | 62.2                     |

From the experiment, 6 K T300 severe corrosion in the oil is very severity, have a great influence on the material tensile strength, especially in the previous month, the tensile strength is down in a straight line, decline down is slow to a month later. Explain T300 6 k material's resistance to corrosion of crude oil is bad, need to improve.

4. Conclusion
- From the point of mechanical properties, tensile strength of T300 6 k room temperature tensile strength is an average of 525 MPa, less than 1/6 of the material standards (3.5GPa), to replace D grade Cr-Mo steel rigid rod, the material strength needs to be improved.
- 6 k T300 tensile strength in 100°C or less is relatively stable, proving that the material high temperature resistant performance is good.
- 6 k T300 is highly affected by the crude oil corrosion on the tensile strength, to adapt to the underground oil production operation environment, must be to improve the resistance to corrosion of crude oil property.

In short, from the point of mechanical properties and corrosion resistance, GH Company’S 6 K T300 can't now replace the rigid rod.

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