Analysis of Serious Deformation of Cavitation Tubing in Salt Cavern Gas Storage in Jianghan Oilfield

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Abstract: Jianghan Oilfield salt cavern gas storage is characterized by depth, high temperature and high pressure. At present, the main problem of Jianghan Oilfield salt cavern gas storage is that in the process of cavitation, the frequent bending deformation at the end of the cavitation tubing string leads to the difficulty of operating the tubing string, which extends the cavitation period and affects the production of the gas storage. The problem of tubing string in the cavitation of salt cavern gas storage in Jianghan Oilfield was counted, and the causes of tubing string bending were analyzed from the aspects of salt layer geological characteristics, tubing string mechanics, fluid mechanics, etc. It was concluded that the injection rate was higher than the critical liquid carrying flow rate, leading to tubing string instability and deformation, which provided theoretical reference for the construction of salt cavern gas storage.

1. Introduction

Deep salt structure is an ideal place for underground storage of natural gas. The selected site of Jianghan Oilfield salt cavern gas storage is Qianjiang Formation in Qianjiang sag of Jianghan Oilfield Basin. Compared with the existing salt cavern gas storage at home and abroad, the selected bed of Jianghan Oilfield salt gas storage site is characterized by large buried depth (2000m), high temperature (83°C), high pressure (32MPa) and so on.

Since 2009, a total of 4 gas storage production Wells have been built, and 25 pipe inspection operations have been carried out in more than 10 years. In 11 of them, tubing string breaking or severe tubing string deformation occurred, which resulted in excessive load during pipe starting, increased operation risks, greatly extended the gas storage construction cycle, and resulted in a sharp increase in the overall cost. In order to solve this problem, it is necessary to study the deformation mechanism of cavitation string in gas storage to avoid string fracture and improve the working capacity.

2. Cavitation mechanism of salt cavern gas storage

In order to effectively control the geometry of the dissolution cavity, the dissolution tube string is designed to be a combination of two strings. It is composed of two parts: one is the center pipe and the other is the middle pipe. The distance between the lower end of the center pipe and the lower end of the middle pipe is two mouth distance, as shown in Fig. 1. Ground water made cavity through the
center pipe into the cavity, brine between pipe and annulus flow from the center to the ground, figure 1 (a), or fresh water from the central tube and pipe ring between the injection, flow from the center pipe, figure 1 (b), after a continuous loop, with control dissolved salt layer, forming a certain cavity shape and volume\(^1\)\(^-\)\(^3\).

![Fig1. Schematic diagram of cavitation string structure of salt cavern gas storage in Jianghan Oilfield](image)

3. There is deformation of tubing string in the process of cavitation

During the construction of salt cavern gas storage in Jianghan Oilfield, the main problem exposed is tubing string deformation in the dissolution stage. Since 2009, there have been 25 pipe inspection operations in 4 gas storage Wells, 11 of which occurred pipe break or severe pipe deformation, as shown in Table 1. Factors that may cause damage to the cavitation string are mainly classified as follows \(^4\):

(1) In the process of cavity dissolution, cavity instability and interlayer collapse will break or crush the cavity dissolution string. In addition, falling laminated insoluble material can squeeze the intracavitary tube, potentially bending the lower end of the hanging string.

(2) Under limited space conditions, the cavity-building string will generally be unstable due to liquid-solid coupling vibration, which will cause excessive pendulum force at the lower end of the string and lead to permanent deformation at the end of the string.

(3) The buckling of the cavity string may be caused by the dead weight, axial stress and strain caused by internal pressure or extrusion, and stress and strain caused by temperature effect.

| NO. | The Year of operation | Problem Centre pipe | Problem Middle pipe | Operation Description |
|-----|-----------------------|---------------------|---------------------|----------------------|
| 1   | 2011                  | deformation         |                     | 3 tubing were seriously bent |
| 2   | 2017                  | deformation         |                     | Tubing break         |
| 3   | 2019                  | deformation         |                     | Tubing break         |
| 4   | 2010                  | deformation         |                     | Tubing bent 20°      |
| 5   | 2011                  | deformation         |                     | 2 tubing bent        |
| 6   | 2018                  | deformation         | deformation         | 3 tubing seriously bent |
| 7   | 2011                  | deformation         |                     | Central tubing seriously bent |
| 8   | 2012                  | deformation         |                     | Central tubing break  |
4. Deformation analysis of cavitation tubing string in gas storage

Jianghan Oilfield gas storage built cavity based on field investigation and analysis of the condition, tubing in the process of bending in addition to build cavity and squeezed by trauma and so on, more important is closely related to the dynamic performance of the tubing string, the string in the limited space of self-excited vibration and instability is the leading cause of serious bent or worn string reason[2]; On the other hand, the comprehensive static state of the tubing string is also an important reason for the deformation. It is proposed to establish a mathematical model from the "virtual force FF" that causes the spiral bending of the free-hanging tubing string, and analyze the causes of the tubing string deformation by analytical method.

(1) Calculation of critical velocity of cavitation tubing

For the critical velocity of the cavitation string, the simplified case is considered. The central pipe is simplified as a cantilever flow pipe from the wellhead to the cavity without considering the space limitation of the outer tube, as shown in Fig. 2.

Figure 2. Central tubular model

For the intermediate pipe, the space limitations of the outer production casing and openhole section are not considered, and the influence of the central pipe is not considered. The fluid participating in vibration is only the fluid in the annulus of the inner and outer pipe.

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\[ u_{cr} = \frac{1.4875 \sqrt{EI}}{l} \]  

According to the above formula, the water injection volume is 40 ~ 100 m³/h and the flow rate of the central tube is 1.37 ~ 3.43 m/s during the construction of water solution cavitation in Jianghan Oilfield. The annular fluid flow rates of the central tube and the middle tube are 1.08 ~ 2.71 m/s, and the flow rate of the middle tube is higher, and the central tube will reach the critical flow rate before the middle tube and become unstable.

(2) Spiral bending of the free-hanging string

As shown in figure 3 a, a string of freedom hanging in the absence of any fluid pipe, if there's one up F the force ACTS on the lower end of the string, the force of compression string, if the force is very
big, lower string will completely into spiral state as shown in figure 3 b, due to the effect of weight of the tubing string, the string force decreases with the increase of the distance from the bottom of the bottom, at neutral point is zero, (Ideally, there is neither tension nor pressure at this point). The string above the neutral point is in a stretch state and is in a straight line. The distance from the bottom of the string to the neutral point N is:

$$n = \frac{F_f}{W}$$  \hspace{1cm} (3)

Where, $F_f$ is compressive force (imaginary force); $W$ is average weight per unit length of the string.

The four effects caused by the change of pressure and temperature: piston effect, spiral bending effect, bulging effect and temperature effect will cause the axial elongation or shortening of the tubing string, and the total length change is written as $\Delta L$.

Tubing string imaginary force $F_f = A_p(P_t - P_0)$, Calculate the force at the end of the string $F = 0.005t$.

The free-hanging string was subjected to four effects, in which the point and position was 2.8m above the lower end of the string.

The cantilever beam model can be used to calculate the external forces on the tubing string under the conditions of different spacing and different deformation angles, as shown in Table 2.

| 4.5in tubing | OD/mm | ID/mm | 10° | 15° | 20° | 25° | 30° |
|--------------|-------|-------|-----|-----|-----|-----|-----|
| 10           | 114.3 | 100.5 | 10.4| 15.6| 20.8| 26.1| 31.3|
| 0            | 114.3 | 100.5 | 2.6 | 3.9 | 5.2 | 6.5 | 7.8 |
| 30           | 114.3 | 100.5 | 1.1 | 1.7 | 2.3 | 2.9 | 3.4 |
| 40           | 114.3 | 100.5 | 0.65| 0.98| 1.3 | 1.63| 1.96|
| 50           | 114.3 | 100.5 | 0.4 | 0.62| 0.83| 1.04| 1.25|

As can be seen from Table 2, the imaginary force on the string is not sufficient to permanently deform the intermediate section at the lower end of the central pipe. According to this, the cantilever string will be unstable due to excessive flow in the actual production process, resulting in bending deformation of the unconstrained part at the lower end of the string.

5. Conclusions and Suggestions
During the construction of salt cavern gas storage in Jianghan Oilfield, the main problem is that the lower end of cavitation tubing string is seriously bent, which affects the process of cavitation and
increases the construction cost. For the salt cavern gas storage with deep burial, high temperature and high pressure, the liquid-solid coupling will cause the instability of the cavitation tubing string under the condition of large injection rate, resulting in the bending deformation of the unconstrained lower end of the tubing string easily, which increases the difficulty of the tubing string pulling out and affects the progress of cavitation operation.

Injection displacement optimization and the speed of water soluble salt research will be the focus, the next step research suggest that the current injection without fully understood the relationship between displacement and speed of soluble salt, reduce the injection displacement, as far as possible on the premise of guarantee of soluble salt rate, to reduce the emissions caused tubing string vibration problem, and reduce the damage of the tubing string, extend the cavity string effectively making cavity cycle, at the same time, coiled tubing with a nozzle can be considered to periodically clean the scaling on the inner wall of the string to shorten the period of cavity construction.

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