Stress Analysis and Creep Life Prediction of Hydrogen Reformer

Furnace Tube

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ABSTRACT: The hydrogen manufacturing converted furnace radiation pipe system is studied as the research object. And the reformer tube has been studied the creep mechanical properties through the furnace tube creep curves under different experimental conditions and experimental data. The stress creep constitutive equation of furnace tube is obtained by the experimental data curve fitting and analysis results. Thermal stress calculation and high temperature creep analysis of the pipe system of hydrogen production equipment were established by thermal elastic plastic increment method. The finite element model of the structure space of the reformer was established by ANSYS software, and the thermal stress and high temperature creep stress analysis were carried out. The calculation results of thermal stress and the stress and deformation of each component after 100 thousand hours of creep were evaluated. Based on the operating conditions of 6 years of service in the past, the calculation method of the remaining life of the furnace tube is established. Its remaining life is 6.3 years. It provides a theoretical basis for the calculation of the remaining life of the equipment, equipment operation and maintenance.

KEYWORDS: Hydrogen reforming furnace; Creep; Residual life; Stress analysis; Thermo-elastic plasticity.

INTRODUCTION

With oil resources dwindling and poor quality of heavy oil trend will become more apparent, Chinese petroleum products continue to improve the quantity and quality requirements, the need to more large-scale hydrogen production unit with suitable, currently about 70% hydrogen from the hydrogen reformer unit [1]. Because hydrogen reformer tube entrance architecture with high temperatures, the high combustion air temperatures and high heat intensity, in the work, thus leading reformer tube temperature creep effect occurs, then the occurrence of failure fracture [2]. Currently, the reformer tube occurs temperature creep analysis and life prediction mainly in three aspects of the simulation carried out with varying degrees of research materials from microscopic experiments, theoretical and numerical.

In the research experiment: Through observed the crystal phase structure characteristic features crack, proposed work should pay attention to the furnace tube operating considerations and temperature limits [3-5]. On the theoretical calculations and numerical simulation methods: the main through structure the tubes at a high temperature furnace tube hoop stress calculations and strength evaluation [6, 7] and numerical simulation of local tubes structure, tubes stress were local Further assessment calculations [8-11] creep stress and their remaining life. However, the above calculation method, only the local tubes on creep properties were analyzed [12, 13], and did not consider the entire hydrogen reformer tubes structure stress state, while, for the tube material in a number of maintenance, open parking after tube remaining life caused by changing the operating status of not considered.

In this paper, based on the entire hydrogen reformer radiant section of tube system for the study, consider the stress state of the structure of the entire tubes system, the establishment of spatial finite element model of the radiant section tubes. And through the high-temperature creep experiments tubes materials, determine tubes materials under normal operating conditions creep performance parameters of tubes materials for high temperature creep analysis, combined with open parking structure tubes maintenance status, assessment tubes remaining life, provide a theoretical basis and reference for the furnace tube life prediction of large-scale hydrogen reformer.

HYDROGEN REFORMER TUBE TEMPERATURE CREEP AND CREEP PROPERTIES OF THE EXPERIMENTAL CALCULATION METHOD

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Under constant load creep generally divided into three stages:

The first stage, in the initial stages of creep, strain rate decreases with time, this phase is generally in a relatively short period of time accomplish.

The second stage, constant strain rate and strain rate at constant develop.

The third stage, the strain rate rapidly increased until failure of the material.

Since the third stage of creep experienced a very short time, the material will fail, usually begin destruction-related (necking, damage), so for the creep analysis of engineering structures, the general choice of first and second creep phase studies. The first stage of the creep strain rate is usually much larger than the secondary creep. Under constant stress, under isothermal uniaxial test conditions, the strain rate is gradually decreased in the first stage, while in the second phase is almost constant, and the first stage of creep time shorter than the second phase.

Hydrogen Reformer Furnace Tube Material Temperature Creep Analysis

Thermal Elastic-plastic Finite Element Method Creep Analysis

Because hydrogen reformer tubes in a long line structure under high temperature conditions, particularly reformer tubes must consider the effect of temperature on the material behavior and structural response. Referring to the abovementioned creep effect showed two phases, namely the redistribution of stresses within the structure and architecture to achieve a stable state of stress, the previous phase of the transient creep state, and then reached the stage of steady creep state.

(1) Thermal elastic-plastic creep theory

As the temperature changes, the material constants such as elastic modulus, Poisson's ratio, yield strength etc will change. Creep deformation of the material $\varepsilon$ can be expressed as the function of temperature $T$, the stress $\sigma$ time $t$:

$$\varepsilon = f(T, \sigma, t)$$ (1)

Creep strain rate is the function of stress $\sigma$, temperature $T$ and time $t$, can be expressed as:

$$\dot{\varepsilon} = f_1(\sigma)f_2(T)f_3(t)$$

Simultaneously conditions for temperature deformation and creep deformation, after the material enters the yield state, the total strain components can be decomposed into:

$$d\{\varepsilon\} = d\{\varepsilon\}_v + d\{\varepsilon\}_p + d\{\varepsilon\}_c + d\{\varepsilon\}_T$$ (2)

In the formula: right parameters are elasticity, plasticity, creep strain and temperature increments.

Where in the temperature strain increment can be expressed as:

$$d\{\varepsilon\}_T = \{\alpha\}dT + (T - T_0)d\alpha$$ (3)

In the formula: $\{\alpha\}$ is thermal expansion coefficient matrix, $T$ is instantaneous temperature, $T_0$ is initial temperature.

Elastic strain obeys Hooke's law:

$$\{\varepsilon\}_e = [D]^{-1}\{\sigma\}$$ (4)

In the formula: $[D]$ is elastic matrix, $\{\sigma\}$ is stress array.

Incremental form
Stress analysis and creep life prediction of hydrogen reformer furnace tube

For plastic materials, plastic strain increment associates with the yield surface, yield surface equation:

\[ F = \bar{\sigma} - H \left[ \int d \bar{\epsilon}_p \right] T = 0 \]  \hspace{1cm} (6)

In the formula: \( \bar{\sigma} \) is equivalent stress, \( d\bar{\epsilon}_p \) is equivalent plastic strain increment.

Therefore, equivalent plastic strain increment:

\[ d\{\epsilon\}_p = d\bar{\epsilon}_p \frac{\partial F}{\partial \{\sigma\}} = d\bar{\epsilon}_p \frac{\partial \bar{\sigma}}{\partial \{\sigma\}} \]  \hspace{1cm} (7)

Assuming creep obeys the law:

\[ d\bar{\epsilon}_c = \phi \left( \bar{\sigma}, \bar{\epsilon}_c, T, t \right) dt \]

In the formula: \( d\bar{\epsilon}_c \) is equivalent creep strain increment, \( \bar{\epsilon}_c \) is equivalent creep strain, \( \bar{\sigma} \) is equivalent stress.

Creep strain increment expressions are similar to the formula (7), can be expressed as:

\[ d\{\epsilon\}_c = d\bar{\epsilon}_c \frac{\partial \bar{\sigma}}{\partial \{\sigma\}} = \phi \left( \bar{\sigma}, \bar{\epsilon}_c, T, t \right) dt \]  \hspace{1cm} (8)

In the formula: \( \{s\} \) is partial array stress.

Putting (3), (5), (7), (8) into equation (2), after finishing get the stress increment:

\[ d\{\sigma\} = [D] \left[ d\{\epsilon\} - d\{\epsilon\}_p - d\{\epsilon\}_c - d\{\epsilon\}_0 \right] - \frac{d[D]}{dT} (\sigma) dT \]

\[ = [D] \left[ d\{\epsilon\} - d\bar{\epsilon}_p \frac{\partial \bar{\sigma}}{\partial \{\sigma\}} - \phi dt \frac{\partial \bar{\sigma}}{\partial \{\sigma\}} - d\{\epsilon\}_0 \right] \]  \hspace{1cm} (9)

In the formula:

\[ d\{\epsilon\}_0 = \left[ \{\alpha\} + (T - T_0) \frac{d\sigma}{dT} \right] dT + \frac{d[D]}{dT} (\sigma) dT \]

Formula (9) is multiplied by \( \frac{\partial \bar{\sigma}}{\partial \{\sigma\}} \), according to the incremental yield surface equation, get \( d\bar{\epsilon}_p \). Taking it into formula (9), get thermal elastic-plastic incremental creep constitutive equation:

\[ d\{\sigma\} = [D]_p \left( d\{\epsilon\} - d\{\epsilon\}_0 - d\{\epsilon\}_c \right) + d\{\epsilon\}_0 \]  \hspace{1cm} (10)

In the formula: \( [D]_p \) is elastic-plastic matrix.

Plastic matrix \( [D]_p \) can be expressed as:
\[
[D]_p = \frac{[D] \frac{\partial \overline{\sigma}}{\partial [\sigma]} \left[ \frac{\partial \overline{\sigma}}{\partial [\sigma]} \right]^T [D]_{\sigma}}{\frac{\partial \overline{\sigma}}{\partial \epsilon_p} + \left[ \frac{\partial \overline{\sigma}}{\partial [\sigma]} \right]^T [D] \frac{\partial \overline{\sigma}}{\partial [\sigma]}
\]

In the formula (10): \( d[\sigma]_0 \) is initial stress increment.

\[d[\sigma]_0 = \frac{[D] \frac{\partial \overline{\sigma}}{\partial [\sigma]} dT \frac{\partial \overline{\sigma}}{\partial [\sigma]} \left[ \frac{\partial \overline{\sigma}}{\partial [\sigma]} \right]^T [D] \frac{\partial \overline{\sigma}}{\partial [\sigma]}\]

Use the Finite Element Analysis Software ANSYS to Analyze the Creep

Finite element analysis of high temperature creep in Section 1.1.1 is based on thermal elastic-plastic incremental creep constitutive equation, use \( \Delta T \), \( \Delta [\sigma] \), \( \Delta [\epsilon] \) instead of \( dT \), \( d[\sigma] \), \( d[\epsilon] \), to linearize incremental constitutive equations.

Elastic region: \( d[\epsilon]_p = 0 \). By the formula (9) to obtain the constitutive equations:

\[\Delta[\sigma] = [D] [\Delta[\epsilon] - \Delta[\epsilon]_0 - \Delta[\epsilon]_x] \]

(13)

Balance equation:

\[\left[K\right] [\Delta[\sigma]] = \Delta[R] + \Delta[R(\Delta[\epsilon]_0)] + \Delta[R(\Delta[\epsilon]_x)]\]

(14)

Plastic zone: by the formula (10) to obtain the constitutive equations:

\[\Delta[\sigma] = [D]_p (\Delta[\epsilon] - \delta[\epsilon]_0 - \Delta[\epsilon]_x) + \Delta[\sigma]_0 \]

(15)

Balance equation:

\[\left[K\right]_p \Delta[\epsilon] = \Delta[R] + \Delta[R(\Delta[\epsilon]_0)] + \Delta[R(\Delta[\epsilon]_x)] - \Delta[R(\Delta[\sigma]_0)]\]

(16)

In the formula: \( \Delta[R(\Delta[\epsilon]_0)] \), \( \Delta[R(\Delta[\epsilon]_x)] \), \( \Delta[R(\Delta[\sigma]_0)] \) is respectively initial temperature strain increment, the creep strain increment beginning and equivalent nodal initial stress caused by load increment, can be expressed as:

\[\Delta[R(\Delta[\epsilon]_0)] = \int [B]^T [D]_p \Delta[\epsilon]_0 dV\]

(17)

\[\Delta[R(\Delta[\epsilon]_x)] = \int [B]^T [D]_p \Delta[\epsilon]_x dV\]

(18)

\[\Delta[R(\Delta[\sigma]_0)] = \int [B]^T \Delta[\sigma]_0 dV\]

(19)

Equivalent creep strain increment can be converted to component:

\[\Delta[\epsilon]_c = \frac{\Delta[\epsilon]_c}{\epsilon_c} \left( 2\epsilon_c^i - \epsilon_c^i - \epsilon_c^i \right)\]

(20)
Stress analysis and creep life prediction of hydrogen reformer furnace tube

\[ \Delta \varepsilon''_y = \frac{\Delta \varepsilon'' (2\varepsilon''_y - \varepsilon''_z - \varepsilon''_x)}{\varepsilon_{\text{el}}} \frac{2(1+\nu)}{2(1+\nu)} \]  \hspace{1cm} (21)

\[ \Delta \varepsilon''_z = -\Delta \varepsilon''_y - \Delta \varepsilon''_x \]  \hspace{1cm} (22)

\[ \Delta \varepsilon''_x = \frac{\Delta \varepsilon''_y}{\varepsilon_{\text{el}}} \frac{3}{2(1+\nu)} \gamma'' \]  \hspace{1cm} (23)

Formula (20) ~ (22) is positive strain components, formula (23) is shear strain components.

By tube thermal elastic-plastic problems caused by high temperature creep, creep strain rate is a function of stress, strain, temperature and time, the paper analyzes the high temperature creep stress analysis of hydrogen plant furnace tube time strengthening creep model selection.

\[ \dot{\varepsilon}'' = C_1 \sigma + C_2 t + C_3 e^{-C_4 t} \]  \hspace{1cm} (24)

In the formula: C1 C2 C3 C4 is creep constitutive equation coefficients, the need for high-temperature creep test tube, by curve fitting the experimental data to determine.

Experimental Research of the Hydrogen Plant Furnace Tube Material Temperature Creep Mechanics

According to structural characteristics of hydrogen reformer tubes, considering the high temperature mechanical properties and deformation under conditions of tube material, now select the reformer tube material 25Cr35NiNb, developed high temperature mechanical test specimens, choose HYC-50 electronic Creep Testing Machine Experimental study on mechanical properties under high temperature conditions of 919℃. Experimental apparatus are shown in Figure 1. The high temperature furnace tube material creep curve is shown in Figure 2.

**Figure 1.** Laboratory instruments external picture.

**Figure 2.** Specimen temperature creep curve.
Using ANSYS program through curve fitting functions, according to the tube material temperature creep curve time to strengthen the creep constitutive equation coefficients, $C_1 = 5.793 \times 10^{-5}$, $C_2 = 3.75$, $C_3 = -0.88$, $C_4 = 1814.5$, formula (25) is fitting creep constitutive equation.

$$
\dot{\varepsilon} = 5.793 \times 10^{-5} \sigma^{3.75} t^{-0.88} e^{\frac{1814.5}{T}}
$$

(25)

HIGH TEMPERATURE CREEP ANALYSIS OF 10×104NM3/H HYDROGEN REFORMER TUBES

Tank Stress Analysis of Numerical Model

This paper studied the shape of the top of the furnace burning stove, according to the $10 \times 104\text{Nm3/h}$ hydrogen reformer engineering drawings, considering the weight of hydrogen reformer, load characteristics and medium pressure tube hangers, choice hydrogen reformer overall for the study, including an inlet manifold system, the tail tube, tube, under a collection tubes, the tubes which the radiant tubes the, tank stress analysis software theory and ANSYS libraries, the whole model is divided into 15905 three units and 22426 nodes, the overall finite element model shown in Figure 3. Wherein the inlet manifold system, the tail tube, tube, under the collecting duct system using tubeline unit, tail tube hanger beams using beam elements, variable force spring hanger, the constant force spring hanger with spring unit.

$10 \times 104\text{Nm3/h}$ hydrogen manufacturing conversion furnace radiant section tubes components of geometric parameters and material parameters are shown in Table 1.

Figure 3. Hydrogen reformer radiant.

Which conversion furnace inlet piping segment operating temperature 630°C, reformer tubes operating temperature 919°C, outlet piping operating temperature of 250°C, pressure piping work are 3 MPa.

Figure 4. Finite element model of the whole section schematic tubes.
Table 1. $10 \times 10^4$ Nm$^3$/h hydrogen reformer radiant section of tubes geometry.

<table>
<thead>
<tr>
<th>Parts</th>
<th>Outside diameter×nominal thickness /mm</th>
<th>Length /mm</th>
<th>Tube number</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet tubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer Line</td>
<td>Φ558.8×22.2</td>
<td>36444</td>
<td>1</td>
<td>TP347H</td>
</tr>
<tr>
<td>Enterance gas collection header tube</td>
<td>Φ558.8×22.2</td>
<td>9638</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Enterance gas collection branch tube</td>
<td>Φ273.1×12.7</td>
<td>18030</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>The tail tube</td>
<td>Φ31.8×2.9</td>
<td>11680</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td>Outlet tubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enterance gas collection branch tube</td>
<td>Φ155.6×19.3</td>
<td>16251</td>
<td>215</td>
<td>25Cr35NiNb</td>
</tr>
<tr>
<td>Enterance gas collection header tube</td>
<td>Φ559×12</td>
<td>14900</td>
<td>5</td>
<td>15CrMoR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$10 \times 10^4$ Nm$^3$/h Hydrogen Reformer Tubes Stress Analysis of Thermal State Operating Conditions

According to numerical calculation model, obtained some data of $10 \times 10^4$ Nm$^3$/h hydrogen reformer, under the operating conditions of the thermal state. The overall equivalent stress are shown in Figure 5, the overall equivalent displacement are shown in Figure 6, and the calculation results of components stress are shown in Table 2.

Seen from Figure 5, the overall equivalent stress distribution are in the range of 0-101 MPa, where the maximum stress occurs on the connecting position between the upper tail tube and the reformer tube. Figure 6 shows that the range of equivalent displacement for the overall model is 0-362.7 mm. From the data in Table 2, we can see that the various stress of inlet and outlet tubes are less than the allowable stress of the material under the corresponding temperature; the equivalent stress of the upper tail tube is 101 MPa, the maximum bending stress is 99 MPa, less than 1.5 times the allowable stress, therefore, under the operating conditions of the thermal state, the stress of the components for tube system can satisfy meet the strength requirements.

High Temperature Creep Analysis Of $10 \times 10^4$Nm$^3$/H Hydrogen Reformer Tubes

According to the geometrical configuration of the $10 \times 104$Nm$^3$/h hydrogen reformer and finite element model established for the study overall, considering the impact of high temperature creep to tube material, the structure of the hydrogen reformer temperature creep analysis, where high-temperature furnace tube material creep curve in Figure 2to select the reference.

![Figure 5. Overall equivalent stress diagram.](image-url)
In order to compare before and after creep, stress changes in the various components of the reformer, will not consider the effect of creep tube consider all components of stress furnace tube creep effects meta-analysis of the results of stress are summarized in Table 3.

Can be seen from the data in Table 3, before and after the creep, the equivalent stress of the oil transfer line, the inlet manifold, and the pig tail tubes are increased slightly, the stress of reformer tubes reduced, and the equivalent stress of the manifold for the hot wall and the cold wall unchanged.

After 100000 h under high temperature creep condition, equivalent stress distribution of reformer tubes are shown in Figure 7, the axial deformation curve with the change of creep time for the top of the reformer tube are shown in Figure 8.

As can be seen from Figures 7 and 8, with the increase of time of furnace tube axial creep deformation is gradually increased, and the rapid increase in axial deformation of creep start time occurs, after about 14,000 hours, the tube axial direction deformation essentially unchanged.
Table 3. $10 \times 10^4$ Nm$^3$/h hydrogen reformer thermal state of the components before and after the stress creep data sheets.

<table>
<thead>
<tr>
<th>Parts</th>
<th>Equivalent</th>
<th>Axial stress</th>
<th>Bending</th>
<th>Hoop stress</th>
<th>Allowable design stress/MPa</th>
<th>Evaluation of the stress intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before creep</td>
<td>After creep</td>
<td>Before creep</td>
<td>After creep</td>
<td>Before creep</td>
<td>After creep</td>
</tr>
<tr>
<td>Transfer Line</td>
<td>57</td>
<td>57</td>
<td>17</td>
<td>17</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>Entrance gas collection header tube</td>
<td>39</td>
<td>42</td>
<td>17</td>
<td>17</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Entrance gas collection branch tube</td>
<td>61</td>
<td>72</td>
<td>14</td>
<td>15</td>
<td>47</td>
<td>60</td>
</tr>
<tr>
<td>The tail tube</td>
<td>101</td>
<td>28</td>
<td>8</td>
<td>8</td>
<td>99</td>
<td>25</td>
</tr>
<tr>
<td>Reformer furnace tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tube1</td>
<td>15</td>
<td>13</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Tube2</td>
<td>15</td>
<td>15</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Adapter tube</td>
<td>26</td>
<td>25</td>
<td>11</td>
<td>11</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Entrance gas collection branch</td>
<td>63</td>
<td>63</td>
<td>33</td>
<td>33</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Entrance gas collection header</td>
<td>50</td>
<td>50</td>
<td>25</td>
<td>25</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 7. Equivalent stress distribution reformer tubes.

Figure 8. Furnace tube point of maximum displacement versus time curve.
HYDROGEN PLANT FURNACE TUBE STRUCTURE TO PREDICT THE REMAINING LIFE OF THE HIGH TEMPERATURE CREEP

According to has been occur refinery maintenance process can know, the paper \(10 \times 10^4 \text{ Nm}^3/\text{h}\) hydrogen reformer tube structure put into use later, hydrogen sulfide materials occur during device repeatedly exceeded, power outages and other accidents, and frequently open parking, so often in the furnace tube non-normal operation conditions, even greater damage to the tube due to creep deformation caused by failure of the furnace tube, and therefore need to determine the extent of the damage and the remaining life of the furnace tube.

The Method of High Temperature Creep Remaining Life Prediction

Life of reformer tube structure often determines the life of the entire hydrogen plant, since the actual work environment, the creep life of the furnace tube is usually a few years or a decade, so long tube creep rupture life data difficult to obtain directly by experiment, only get short-term creep test data material by increasing the stress and temperature method, and then uses the persistent strength of the outer tube of the push to predict long-lasting life. Therefore, it is proposed the use of a variety of short-term accelerated test data extrapolated material under actual working conditions long creep properties of methods, such as creep damage mechanics, lasting strength method, Larson-Miller parameter method. Currently, Larson-Miller parameter method (referred to LM method) is widely used for predicting the creep rupture life.

Larson-Miller (LM) method, also known as parametric method, the basic idea of the method by increasing the test temperature, the material bound to change the internal structure, it is possible with higher temperatures and shorter time data acquired to estimate the long-serving state at lower temperatures, the L-M parameter represents the formula:

\[
P = T(C + \lg t)
\]  

(26)

In the formula: \(t\) is the creep rupture life, h.

Hydrogen Reformer Furnace Tube Remaining Creep Life Prediction

The Method of Hydrogen Reformer Furnace Tube Remaining Life Calculation

In the prediction of the remaining lifetime of the furnace tube, many uncertain factors are included. For example, when the detection for tube thickness or diameter are the main considered factors, the damage of the furnace tube should be estimated according to the previous change of operating conditions such as operating pressure, temperature of furnace tube and corrosion rate, and that's the life exhaustion fraction. The sum of exhaustion lifetime fraction for the furnace tube is the gross value of damage accumulation, the remaining lifetime fraction can be calculated by using 1 minus the gross value of the damage, and finally the remaining life fraction is converted into the expected life estimate value under a predetermined operating condition.

By hydrogen reformer tubes work over the past 6 years of service time to calculate, will be divided into four different operating cycles, the past operating conditions of furnace tube as shown in Table 4.

<table>
<thead>
<tr>
<th>Operation cycle</th>
<th>Time of duration /a</th>
<th>Operating pressure /MPa</th>
<th>Metal tube shell temperature /℃</th>
<th>Minimum thickness /mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Early operation</td>
</tr>
<tr>
<td>1</td>
<td>1.2</td>
<td>2.99</td>
<td>919</td>
<td>14.3</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>3.01</td>
<td>920</td>
<td>14.1</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>3.03</td>
<td>922</td>
<td>13.7</td>
</tr>
<tr>
<td>4</td>
<td>1.6</td>
<td>3.02</td>
<td>921</td>
<td>13.6</td>
</tr>
</tbody>
</table>

Note: "a" is the sign of "year" in the International System of Units.

Different lengths of time for each cycle of operation, the operating cycle length selected depends on the pressure and temperature changes, and the operating pressure of each cycle, the metal temperature is assumed to be constant, its values chosen are representative of typical values. Tube thickness estimation process assumes an outer diameter
remains unchanged.

Reference SH/T3037-2002, which is Refinery Furnace wall thickness calculation, standard mechanical properties and high temperature creep test data, the furnace tube (25Cr35NiNb) in the work service 100000h average minimum breaking strength or Larson-Miller parameters curve, as shown in Figure 9.

Reference SH/T3037-2002 "Refinery Furnace wall thickness calculation" standard mechanical properties and high temperature creep test data, combined with tube material (25Cr35NiNb) Larson - Miller parameter curves. Calculated according to the furnace tube metal temperature Td and design rupture life tDL, formula (26) was:

\[ P = (T_d + 273)(C_{LM} + \lg t_{DL}) \times 10^{-3} \]  

(27)

In the formula: CLM is Larson-Miller constant, CLM=20.

The minimum or average Larson-Miller is valued by the minimum or the average breaking strength Larsen-Miller parameters used average stress to determine, the average stress creep stress by 2.3 tube each time period calculation results, the average stress and intensity obtained are shown in Table 5, where the safety factor of 1.5. Using Larson-Miller value and each cycle of tube metal temperature, the minimum or average breaking time can be calculated separately through Larson-Miller parameter equation.

**Hydrogen Reformer Furnace Tube Remaining Life Calculation**

In the first operation cycle, for example, explain the process of furnace tube residual life calculation. According to creep stress within the first cycle of 2.3 section calculated, by tube material (25Cr35NiNb) obtain the minimum Larson - Miller is 29.71, tube temperature 919°C,

\[ 29.71 = (919 + 273)(20 + \lg t_{DL}) \times 10^{-3} \]

Obtain

\[ \lg t_{DL} = 4.92 \]

So get a minimum breaking strength of life:

\[ t_{DL} = 8.4 \times 10^{-4} h = 9.6 a \]

Each period of the exhaustion of the life cycle of each fraction \( \eta_i \) can be calculated for, i represents the operation cycle, end of the life cycle of the fraction \( \eta_i \) may be the operation period of time divided by the corresponding rupture life derived. Thus the minimum-rupture life of the above calculations, the lifetime score is obtained first operation cycle.

\[ \eta_i = 1.2/9.6 = 0.125 \]

Similarly, the corresponding fracture time and the life fraction were calculated according to the average intensity, and then adopted the same method to calculate corresponding minimum or average fracture time and life fraction of each operating cycle, the calculation results are shown in Table 5.

**Table 5. Break time for each operating cycle and life scores.**

<table>
<thead>
<tr>
<th>Operation cycle</th>
<th>Average intensity /MPa</th>
<th>Intension/MPa</th>
<th>Larson-Miller value/°C</th>
<th>Rupture life calculate by minimum intensity</th>
<th>Rupture life calculate by average intensity</th>
</tr>
</thead>
<tbody>
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Therefore, the remaining life of the furnace tube if scores by calculating a minimum breaking strength of 0.51, if the average breaking strength was calculated as 0.78. In actual industrial production, the remaining life of tubes systems shall be calculated minimum breaking strength is calculated, the remaining life of 6.3 years.

CONCLUSIONS

(1) Through experimental study the mechanical properties of high-temperature creep of tube material obtained creep curves and experimental data tubes under high temperature conditions, and curve fitting experimental data to obtain creep constitutive equation. Provide reliable mechanical performance parameters for the creep stress analysis and strength evaluation.

(2) According to the structural characteristics of $10 \times 104\text{Nm}/\text{h}$ hydrogen plant tubes and geometric parameters, establishment of spatial finite element model, calculated deformation and stress calculations hot operating conditions of the components, by evaluating the stress of the various components stresses were within the allowable stress range, to meet the strength requirements.

(3) The use of fitting creep constitutive equation, the structure of the high-temperature furnace tube creep stress analysis, creep stress and creep deformation of the components after the hydrogen plant and make a strength evaluation are to meet safety and operational requirements.

(4) According to the service has been working for six years in different hydrogen furnace tube creep cycle operating conditions and tube material corresponding Larson-Miller curve parameters formula, calculate the remaining life of the tube came out different cycle scores, and then get the remaining life of the furnace tube was 6.3 years.

CONFLICT OF INTEREST

This article content has no conflict of interest.

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