Safety Assessment of Pressure Vessels Exceeding the Design Service Life of a Petrochemical Company's Rubber Plant

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Abstract. The rubber plant of a petrochemical company has been built for a long time, some pressure vessels have exceeded the design service life or 20 years. It belongs to the pressure vessel beyond the design service life. A large number of devices and pressure vessels have entered or are about to enter the extended service stage. The detailed safety assessment of all equipment in service beyond the time limit is costly, inefficient and not targeted. Therefore, in this paper, through the screening of time-dependent damage modes. Focus on safety assessment of equipment with time-dependent damage such as corrosion, fatigue and creep. According to the screening and evaluation results, the safety assessment results and inspection management suggestions of the pressure vessel of the whole set of equipment are given. It is hoped that it can provide a reference for enterprises to manage the safety of pressure vessels beyond the design service life.

1. Introduction

The so-called over-service pressure vessel, according to the provisions of Article 7.1.7 of TSG 21-2016 of the Supervision Regulation on Safety Technology for Stationary Pressure Vessel, is to reach the design service life, or the design service life is not specified. But pressure vessels that have been used for more than 20 years. If the pressure vessel is to continue to be used, the user unit shall entrust an institution with inspection qualification to carry out inspection according to relevant regulations, conduct safety assessment if necessary(suitable for use evaluation)[1-2].

2. Safety assessment object

According to the data of pressure vessels beyond the design service life provided by the rubber plant of a petrochemical company, there are 228 pressure vessels exceeding the design service life, include butadiene workshop, tank farm workshop, and so on.

3. Technical route of safety assessment

Aiming at the problem of safety assessment of pressure vessels beyond the design service life of a petrochemical company's rubber plant, based on scientific research and technological achievements, solve the problem of continuous operation and management of pressure vessels beyond the design service life for enterprises. According to the "13th Five-Year Plan" national key research and development project "Life prediction and key technology research of life extension of pressure equipment in extended service" Results of (Subject No：2016YFC0801905) "Safety Classification Method for Over-service Pressure Equipment Based on Damage Mode and Residual Life Prediction", in combination with GB/T 30579-2022 Damage Modes Identification for Pressure Equipments, we will transform scientific and technological achievements[3-4]. The general procedures for safety assessment of pressure vessels beyond the design service life include: data review and operation investigation, damage mode identification, judgment of whether the damage mode is related to time, analysis and inspection of the correlation between the damage mode and the expected service life, and suggestions for use and maintenance, etc. If necessary, the identified damage mode (mechanism) shall be quantitatively evaluated, as shown in Figure 1.

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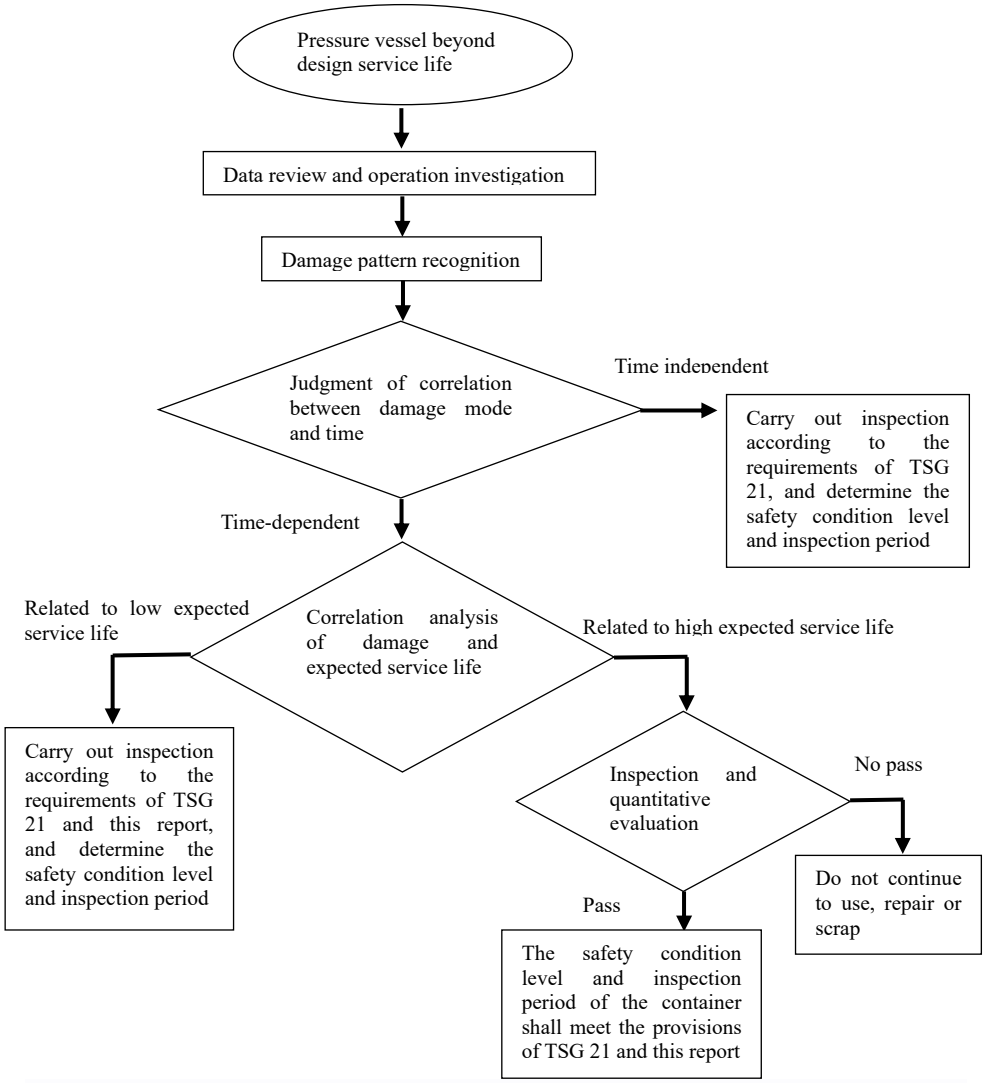

Figure1. Technical flow chart of safety assessment for pressure vessels beyond design service life

4.Data review and process operation investigation

(1) Investigate the construction, operation and maintenance data (data) affecting the service life of pressure vessels, mainly including:

a) Design, manufacturing (installation), repair and transformation data of pressure vessels;

b) Process design and operation data;

c) Maintenance management (inspection, detection and maintenance) data, etc.

(2) Design (pressure vessel, process), manufacturing (installation) data:

a) Pressure vessel design drawings, strength calculations and operation instructions;

b) Pressure vessel quality certificate, as-built drawing, etc;

c) Installation (including on-site assembly) data;

d) Transformation (including process) and maintenance data.

(3) Operation data:

a) General data of plants, equipment and devices, including climate, atmospheric environment and geological conditions[5];

b) The composition and physical parameters of medium fluid (including corrosive and toxic media), and the change of medium composition and content during the use of pressure vessels shall be considered;

c) For pressure vessels that have been modified, moved and used, their historical service conditions must be investigated;

d) Operation log and process record;

e) Operation records, startup and shutdown records and abnormal condition records, etc.

(4) Maintenance management (inspection, detection and maintenance) data:

a) "Use Registration Certificate", "Special Equipment Use Registration Form" and other registration materials;

b) The last two valid periodic inspection reports.

5. Damage pattern recognition

On the basis of GB/T30579-2022 comprehensive analysis of potential damage modes, the potential damage modes of pressure equipment in service under specific working conditions include the following five categories[6-8]:

(1) Corrosion thinning: wall thickness thinning caused by metal loss under the action of corrosive media;

(2) Environmental cracking: cracking of materials under service environment;

(3) Material deterioration: due to the degradation of the microstructure, mechanical/corrosion resistance of the material under the service environment;

(4) Mechanical damage: the reduction of bearing capacity of materials under mechanical load or thermal load;

(5) Other damage: damage modes not included in the above four categories.

Combined with the materials, process, logistics, corrosive media, operating conditions, medium flow rate and other aspects of the pressure vessel evaluated, corrosion thinning in the damage mode of pressure vessels beyond the design service life of the rubber plant mainly includes: atmospheric corrosion (with/without insulation layer), organic acid corrosion, alkali corrosion, cooling water corrosion, etc. Environmental cracking mainly includes: ammonia stress corrosion cracking, alkali stress corrosion cracking, chloride stress corrosion cracking and wet hydrogen sulfide damage, etc. Mechanical damage includes: mechanical fatigue.

6. Classification of time-dependent damage modes

See Table 1 for typical time-dependent damage modes.

Table 1. Typical time-dependent damage modes

Order number	Damage mode	Typical damage morphology
1	Damage mode	Uniform thinning or local thinning, scattered spot corrosion
2	tired	Surface cracking, buried defect propagation

According to the results of damage pattern identification, the damage modes of pressure vessels are further classified into time-dependent and time-dependent damage modes. In the damage modes related to pressure vessels beyond the design service life of the rubber plant, atmospheric corrosion (with/without insulation layer), organic acid corrosion, alkali corrosion and cooling water corrosion belong to corrosion thinning. Mechanical fatigue belongs to fatigue, both damage modes are time dependent; ammonia stress corrosion cracking, alkali stress corrosion cracking. The damage modes of environmental cracking such as chloride stress corrosion cracking and wet hydrogen sulfide damage are independent of time[9].

7. Correlation analysis with expected service life

Through data review of pressure vessels beyond the design service life, investigation of process operation, damage mode analysis and on-site data collection, pressure vessels with time-dependent damage modes are divided into two categories: those related to low expected service life and those related to high expected service life.

7.1 Corrosion thinning

For non-lined and composite plate pressure vessels, when the wall thickness loss does not exceed 75% of the design corrosion allowance, pressure vessels can be classified as related to low expected service life, otherwise, it is classified as highly correlated. For lined or composite plate pressure vessels, when the wall thickness loss does not exceed 25% of the thickness of the lining plate or cladding material, and the corrosion rate has no trend of increasing year by year during use, pressure vessels can be classified as related to low expected service life. Otherwise, it is classified as highly correlated.

Check the latest inspection report of pressure vessels beyond the design service life, the corrosion thinning damage mode of 20 pressure vessels beyond the design service life is related to the high expected service life.

7.2 Fatigue

Because the spherical tank may have certain pressure fluctuations during use (Start/stop and filling process), it is conservative to think that there is mechanical fatigue, 26 spherical tanks involved in the project.

The fatigue damage assessment of 26 spherical tanks was carried out by using the fatigue strength calculation method in JB 4732-1995 standard. According to the requirements of JB 4732, when the operating conditions of spherical tank meet all requirements of 3.10.1, 3.10.2.1, 3.10.2.2 or 3.10.3 in JB 4732-1995, fatigue assessment can be avoided. It can be seen from the operating conditions of 26 spherical tanks, the 26 spherical tanks meet all the provisions of 3.10.2.1 in JB 4732-1995, namely: for steel with normal temperature tensile strength Rm $\leqslant$ 550MPa, number of pressure cycles in the full range of startup and shutdown, prediction of working pressure cycle with pressure fluctuation range exceeding 20% of design pressure (Design) number of times, the sum of effective times of metal temperature difference fluctuation between any two adjacent points, including nozzle, shall not exceed 1000, therefore, 26 spherical tanks can be exempted from fatigue assessment.

Pressure vessels that meet the conditions of exemption from fatigue analysis in JB/T4732 according to actual operating conditions can be classified as related to low expected service life, therefore, the fatigue damage mode of 26 spherical tanks involved in the project is related to the low expected service life[10].

8. Quantitative evaluation

8.1 Scope of quantitative evaluation

Confirm the scope of quantitative evaluation by analyzing the correlation between the damage mode and the expected service life of 228 pressure vessels beyond the design service life in the rubber plant:

(1) 20 pressure vessels with corrosion thinning damage mode related to high expected service life;

(2) The original data is insufficient, and one nitrogen buffer tank (V0-714) with nominal wall thickness is not found;

(3) Pressure vessels with cracks found during inspection or operation, although the crack has been repaired and the repair is qualified. However, in order to evaluate the safety of its continuous operation, three pressure vessels (one of which has both corrosion thinning and cracking) with cracks have been quantitatively evaluated.

According to the above quantitative evaluation scope, among 228 pressure vessels exceeding the design service life in the rubber plant, there are 23 pressure vessels requiring quantitative evaluation.

8.2 Quantitative evaluation results

For 20 pressure vessels and nitrogen buffer tanks V0-714 with corrosion thinning damage mode and high expected service life, evaluation of uniform thinning according to GB/T 35013.

For 3 pressure vessels with cracking damage or crack-like defects（V-206B、E-2012R-709D）, Its cracks have been eliminated, carry out tolerance analysis for three pressure vessels according to GB/T 19624-2019, give the damage tolerance in the next inspection period.

The quantitative evaluation results of 23 containers are all qualified.

9. Conclusions and suggestions

Comprehensive data review and operation investigation, damage pattern recognition, determine whether the damage pattern is time dependent, analysis and quantitative evaluation results of correlation between damage patterns and life expectancy. The following safety assessment conclusions are obtained:

(1) Safety assessment of 228 pressure vessels beyond design life, its original data are provided by the user unit. According to the provisions of Article 54 of the 《Special Equipment Safety Law of the People's Republic of China》,the user is responsible for the accuracy of the data provided.

(2) 228 pressure vessels beyond the design service life of a petrochemical company rubber plant evaluated, among the main damage modes, the time-dependent damage modes are: corrosion thinning（including: atmospheric corrosion (with/without insulation layer),organic acid corrosion, alkali corrosion, cooling water corrosion, etc）. And fatigue (mechanical fatigue), environmental cracking is independent of time（including: ammonia stress corrosion cracking, alkali stress corrosion cracking, chloride stress corrosion cracking and wet hydrogen sulfide damage, etc）.

(3) Of 228 pressure vessels, 207 are related to low damage mode and expected service life, 20 pressure vessels with high damage mode and expected service life. Due to insufficient original data,1 pressure vessel that can not judge the correlation between damage mode and expected service life.

(4) For 20 sets, it is related to high service life, and 1 set with incomplete data, three pressure vessels with cracks (one of which has corrosion thinning at the same time)，23 sets in total for quantitative evaluation, the evaluation results are all passed.

(5) 228 pressure vessels beyond the design service life in the rubber plant have passed the safety assessment, continue to use according to the safety condition level and inspection cycle determined in the latest periodic inspection report. After expiration, the enterprise shall organize relevant qualified units to carry out inspection according to the requirements of TSG 21 and this report.

(6) For pressure vessels with high expected service life，corresponding monitoring means should be added, guarantee the safe operation of equipment.

According to the safety assessment of pressure vessels exceeding the design service life of a petrochemical company's rubber plant, the following suggestions are put forward for equipment use:

(1) Pressure vessels beyond design service life shall be identified according to damage mode, results of damage assessment and classification of correlation between pressure vessel and expected service life, prepare inspection plan one by one, implement inspection，and issue inspection report.

(2) The rubber plant should pay attention to the annual inspection of equipment, the annual inspection items are mainly macro inspection. For parts with external corrosion found in annual inspection, conduct thickness measurement to determine whether the equipment wall thickness meets the operating requirements.

(3) It shall operate in strict accordance with the design conditions，control the amplitude of process fluctuation，pay attention to the possible impact of process fluctuation on the equipment.

(4) The period of startup and shutdown is the period of equipment failure，detailed and clear startup and shutdown plan shall be prepared for the startup and shutdown of the device，and accident emergency treatment methods.

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