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Residual Strength Analysis of Three-phase Separator Containing Corrosion Defects in Service

C.J. Han[1], R. Xie[1], Y. Xiao[1], J. Zhang[1,2*]
1.School of Mechatronic Engineering, Southwest Petroleum University, Chengdu, China
2.Key Laboratory of Energy Engineering Safety and Disaster Mechanics （Sichuan University）, Ministry of Education , Chengdu, China.
*J. Zhang, longmenshao@163.com

Abstract

Three-phase separator, for separating oil, gas, water three-phase and solid phase, is widely used in oil field development and production process. Since the long-term effects of oil and gas in an aqueous medium, the inside of the three-phase separator usually corrodes, thus, reduce its loading capacity and its service life, and endanger the safety of equipment and oil and gas production system. Based on, the paper set up a simulation model of the three-phase separator containing the problem of corrosion defects, and made model analysis on the residual intensity of the three-phase separator containing corrosion defects. Analysed the impact of position and geometry on the residual intensity of the three-phase separator. The result as follows: plastic deformation of the cylinder corrosion defects region primarily occurs at the axial edges of the defect. As the defect length, width, depth enlarged, the separator failure occurs earlier, among which the depth of defects impact greatest on the failure pressure. Plastic deformation of the corrosion defects head region occurs first in the centre of the defect, and extends to the surrounding. The larger the depth and cross-sectional area of the defect is, the sooner separator failure occurs, wherein the depth of defects impact greatest on the failure pressure. The impact of the head defects overpassed that of the cylinder defects on the residual intensity of the three-phase separator.

Keywords: Three-phase separator; corrosion defects; residual intensity; finite element analysis

Introduction

The three-phase separator is to rely on the incompatibility and the density difference among oil, gas and water. It is suitable for the purification of high water content well, especially oil and gas well containing a large amount of free water, as is shown in Fig.1. In the process of oil and gas field development and production, three-phase separator is one of the most important equipment in oil and gas water separation, and it also to ensure that the output of crude oil and withdrawal of water are up to standard [1]. Therefore safety performance and service life of oil gas water separator have an important influence on oil and gas field development, However, under service condition, due to the mixed effects of oil, gas, water and other material, the internal wall of the three-phase separator face seriously corrodes and local residual strength decreases significantly, so this has seriously endangered the safe operation of the separator. The corrosion mainly concentrates in the water chamber of the floating ball, the bottom of the separator, coalescence plate and the circumferential weld, internal support, oil pipelines, water pipelines, oil-water interface and other parts. According to the corrosion factors of the three-phase separator, the researchers launches a series of research work, they combine the research with the results of the analysis and put forward many feasible protective measures [2].but the operation process to ensure real-time monitoring of residual strength is still relatively small, and the crevice corrosion [3], bacterial corrosion and internal structure defects will make local wall thinner, leading to the insufficient of local strength to some unknown degree. There are serious security risks in the three-phase separator under service condition.

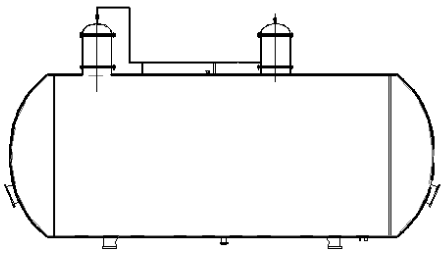

Fig.1 The structure of three-phase separator

Understand the development situation of corrosion of the three-phase separator to ensure its safe operation. It often appears to induce accidents, causing serious economic loss and personnel injury [4]. If focusing on detection and maintenance, some oil and gas fields have less spare separator configuration the construction, some oil and gas even don't have separator as spare one. This may lead to a halt in production for detection, so it is necessary to predict the corrosion rate and analyze the changes of the residual strength evaluation of three-phase separator caused by corrosion so as to assess the safe operation of life expectancy of separator. And the corrosion rate of oil and gas separator can usually be specific through continuous statistics or indoor safety testing data of simulated corrosion experiments, this paper mainly discusses the determination of residual strength of corrosion state of separator.

Building Finite Element Models

Finite element analysis (FEA Finite, Element Analysis) is a method of using mathematical approximation to simulate the realistic objects of the physical system, including geometry and loading conditions. It replaces complicated problems with a relatively simple one and then solve it [5]. Finite element method can get rid of a lot of difficult field operation, using simulation to replace the actual situation. Therefore, through the establishment of numerical model of three-phase separator containing corrosion defects, this paper analyses residual strength of three-phase separator on corroded defects by using finite element software. Besides, it also studies the rule of the influence that corrosion defect position and size changes have on the residual strength of the three-phase separator, when the position and size of corrosion defects change.

Physical model

The purpose of this paper is to analyze the influence of corrosion defects of three-phase separator and cylinder head residual strength, so it can be simplified as the actual three-phase separator as is shown in Fig.2. The analysis model is based on an three-phase separator on service. So it can describe the corrosion defect accurately and can ensure accuracy of calculation result [8-10].

Fig.2 Simplified model of the three - phase separator

The separator is affected by internal pressure, and when the internal pressure is 4MPa, we can calculate the two-way stress according to the formula (1) and formula (2).

$$\sigma' = \frac{Pd}{4\delta} = \frac{4 \times 10^{6} \times 2200 \times 10^{-3}}{4 \times 16 \times 10^{-3}} = 137.5MPa \qquad (1)$$

$$\sigma'' = \frac{Pd}{2\delta} = \frac{4 \times 10^{6} \times 2200 \times 10^{-3}}{2 \times 16 \times 10^{-3}} = 275MPa \qquad (2)$$

Where, σ' is tensile stress, MPa. σ'' is tangential stress, MPa. d is three-phase separator cylinder diameter, mm. P is internal pressure of three-phase separator, MPa. δ is three-phase separator thickness, mm.

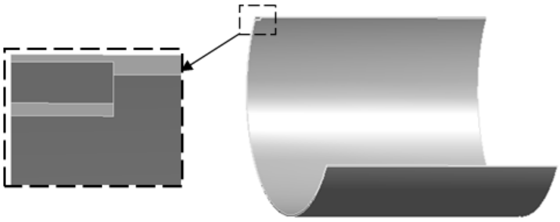

Fig.3 Finite element analysis model of corrosion defects on cylinder

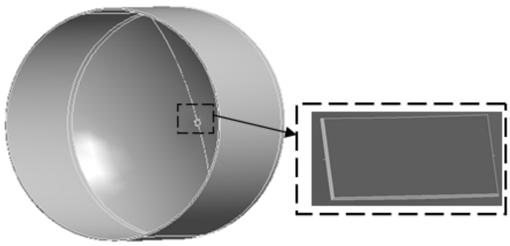

Fig.4 Finite element analysis model of corrosion defects on head

Under the actual conditions, because the stress received by the corrosion near defect is bigger, so in the presence of corrosion defects, corrosion defects of three-phase separator and the area around it damaged first, simulation analysis usually selects the part of cylinder head of a section or the part containing corrosion defects. Since corrosion of the main defects in the three-phase separator of is square or round, so according to the symmetry characteristics of the model, the separator barrel body segment model 1/4 is selected to analyse [5]. In the inner surface of cylinder head section and the top model of the three-phase separator were established the square cylinder in the analysis of the corrosion pits. When some defect areas are affected, take the 1/4 model of the barrel to fill the corrosion pit evenly, as is shown in Fig.3. Change the position of corrosion defects to the inner surface of the top of head position, when head position in the analysis of the defect area is affected, the entire head and a separator cylinder are to establish analysis model as is shown in Fig.4.

Applied load process

Apply the displacement constraints in section in the contact head and cylinder. Limit axial displacement is zero. Apply the frictionless constraint in the head section which is parallel

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to the axial direction. And the four inner surface defects are applied 4MPa internal pressure in the model. The operating pressure presents a linear increase in the 10s from 0MPa to 4MPa.

Failure criteria

Allowable stress is the ultimate strength of materials under different conditions and working conditions, calculated according to formula (3).

For plastic material:

$$[\sigma] = \frac{\sigma_s}{n_s} \qquad (3)$$

Where, $[\sigma]$ is the allowable stress, MPa. σ_s is the yield strength, MPa. n_s is the safety factor, under static loading, safety factor of plastic material is $n_s = 1.2 \sim 2.5$.

The allowable stress is the highest limit of the working stress of the component, that is to say the working stress is not more than the allowable stress. Therefore $\sigma \le [\sigma]$, the strength condition can be checked according to the strength to confirm the allowable load.

Considering the material, the applied load, the component simplification, the reasonable degree, the importance of the component in the equipment and the working conditions, and combining the practical experience, the safety factor $n_s = 1.45$ is selected. The yield stress $\sigma_s = 245MPa$ of the Q245R material is introduced into (3) and the allowable stress is calculated through formula (4), and the safety of the in-service three-phase separator with 170MPa is evaluated.

$$[\sigma] = \frac{\sigma_s}{n_s} = \frac{245MPa}{1.45} = 170MPa \qquad (4)$$

Simulation calculation of defect parameter setting

Table 1 Geometric parameters of corrosion defect on cylinder

Defect size	Length（mm）	Width（mm）	depth（mm）
Length change	60、100、140、180、220、260	50	8
Width change	100	30、50、70、90、110、	8

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		130	
Depth change	100	50	6、8、10、12

Based on the effect the establishment of corrosion defects have on the separator simulation analysis, the design is shown in Table 1 and table 2. It shows multiple defect geometric parameters and comparatively analyses the influence of geometric parameters has on the residual strength of corrosion defects of separator.

Table 2 Geometric parameters of corrosion defect on head

Group	Defect length （mm）	Defect width （mm）	Defect depth （mm）
1	50	50	8
2	75	75	8
3	100	100	8
4	50	50	6
5	50	50	10
6	100	100	8

Simulation results analysis

Influence of corrosion defect location

As is shown in Fig.5, when the same corrosion defect is located in the cylinder and the head position, equivalent stress nephogram of corrosion region under the pressure 4MPa is listed. It can be seen from Fig.6, the maximum stress and the equivalent stress of the corrosion defects of the cylinder are not the same as those of the head area. It describes the relationship between the two positions of the corrosion area of the maximum equivalent stress with inner pressure in the range of 0-4MPa. From Fig.6, in the early stages of inner pressure load application, the curves of the maximum equivalent of the two corrosion area almost overlap, but with the increase of working pressure, maximal equivalent stress of head defects gradually gets away from the cylinder defects and is greater than that of cylinder defect area. From the Figure we can see, when the internal pressure reaches about 1.48MPa, the equivalent of two defects stress showed small fluctuations, this is because the

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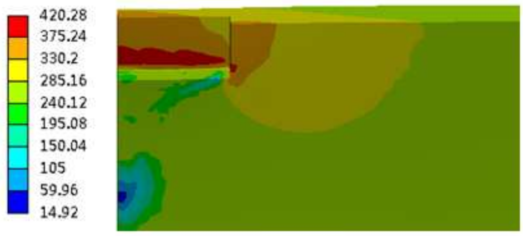
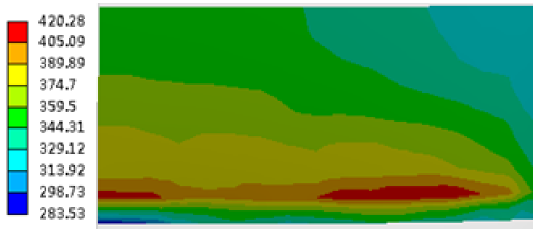
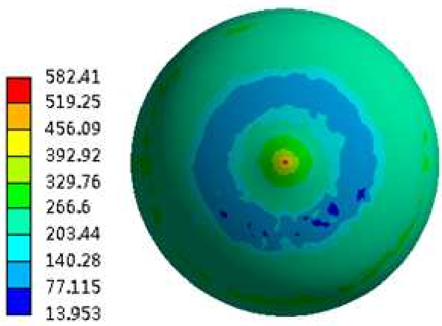
separator material enters the yield limit and causes the phenomenon. In addition, in the early stage of the increase of internal pressure, the two position defect areas' maximum equivalent stress approximately grow linearly, the head of corrosion defect area' equivalent pressure is to achieve the maximum yield strength. It is earlier than cylinder corrosion defects to enter the yield stage. In the middle stage, it fluctuates in a small range. With the increase of internal pressure, the maximum equivalent pressure of the head of the corrosion region is to achieve ultimate tensile strength earlier, than the cylinder corrosion defects damage.



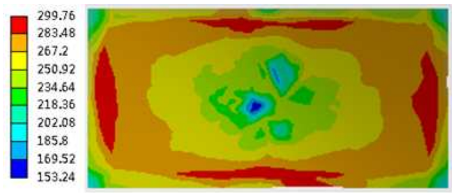
(a) Internal of cylinder defect



(b)Inner surface of cylinder defect



(c) External of head defect



(d) Outer surface of head defect

Fig.5 Equivalent stress cloud diagram of the corrode area at different positions of defect

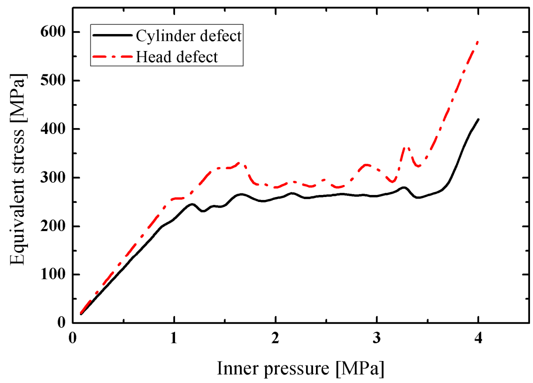


Fig.6 The relation of the maximum equivalent stress with work pressure

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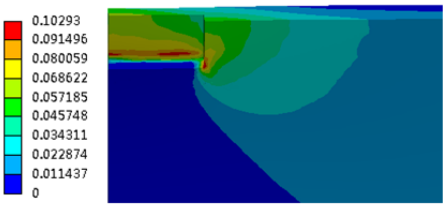
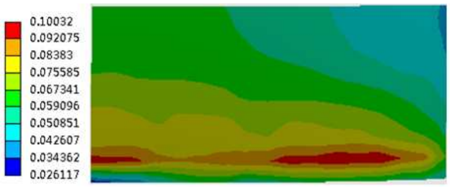
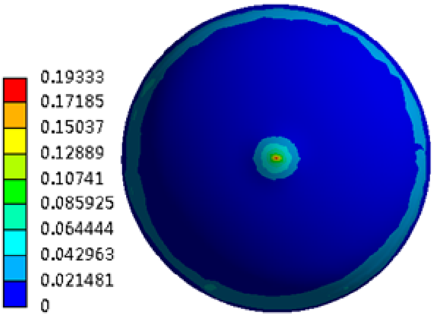


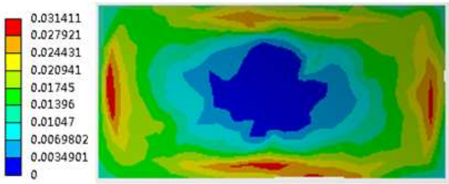
(a) Internal of cylinder defect



(b)Inner surface of cylinder defect



(c) External of head defect



(d) Outer surface of head defect

Fig.7 Plastic strain nephogram at different positions of defect

Fig.7 shows equivalent plastic strain distributions under the operation pressure 4MPa, when the corrosion defects with the same geometric size are located respectively in the cylinder and head, the corrosion area of. The two positions' equivalent stress nephogram are alike the two positions' equivalent plastic strain distribution and the maximum equivalent plastic strain are not the same. The strain distribution of the defect area of cylinder decreases from the edge to the central axial and the strain distribution of defect region of head decreases from the defect centre to the periphery ring.

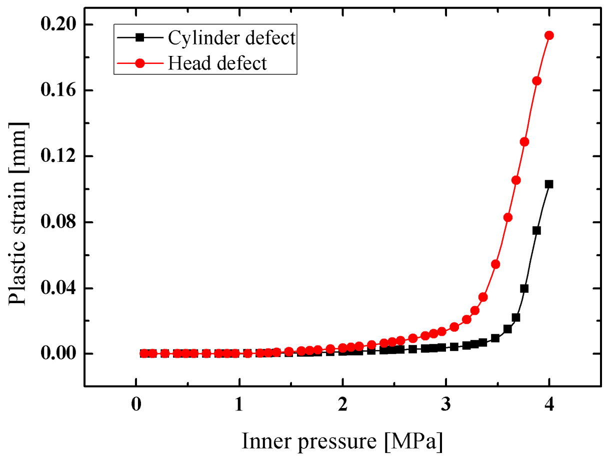


Fig.8 The relation of the maximum strain with work pressure

In addition, as is shown in Fig.8, when internal pressure was in the range of 0-4MPa, cylinder and head defect areas' maximum equivalent plastic strain varies with the increase of working pressure. From Fig.8, the defect area and cylinder head, the positions' maximum equivalent plastic strain increases with the increase of the working pressure, the trends are similar. But in the head position of the corrosion defect under the working pressure1.68MPa, the corrosion area of the maximum equivalent plastic strain increases slightly after the start. When the work pressure is 3.28MPa, the maximum equivalent plastic strain similar to the exponential function increases rapidly; while in the corrosion defect barrel location reaches 2.48MPa under the working pressure, the corrosion area the maximum equivalent plastic strain begin to increase slightly, the internal pressure increases to 3.68MPa, the plastic strain similar to the exponential function increases rapidly, and the corrosion defect area increases later than that of the head position. In addition, the maximum equivalent of head corrosion defect area' maximum equivalent plastic strain is larger than that of the cylinder defect stress. so it shows that the effect of corrosion defects in head position have bigger effect on the wind sharp plastic deformation, which will more easily lead to failure of the separator due to the deformation and failure of head position.

Table 3 Failure pressure of different defective position

positions of defect	The allowable stress value(MPa)	Failure pressure (MPa)
cylinder defect	170	0.75
head defect	170	0.65

When the maximum equivalent stress reaches the corrosion area of the three-phase separator material allowable stress, three-phase separator is in dangerous working conditions, there is a high possibility of failure, the working pressure is the failure pressure at that time. Through the finite element analysis results of the post-processing failure pressure of the same size square defects respectively in three-phase' cylinder and head is calculated, as is shown in Table 3. From the data it can be found that compared with the cylinder position of corrosion defects, defects in the head position have failure pressure earlier, that is to say, it is more prone to have failure deformation. In addition, in the absence of corrosion conditions, separator working pressure is 1MPa, and in the presence of corrosion defects afterwards, the failure pressures of the cylinder and the head position are both less than 1MPa, so the corrosion defects will reduce the separator work and influence the normal operation of the separator.

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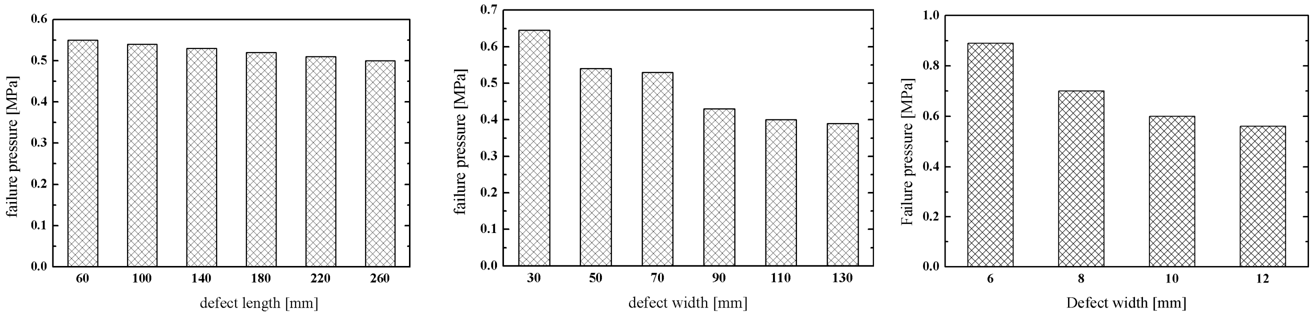
Influence of corrosion defect location



（a）Corrosion length （b）Corrosion width （c）Corrosion depth

Fig.9 Influence of geometric parameters about corrosion defect of cylinder

In order to analyse the influence of corrosion defects of different geometrical size have on the failure pressure of the separator, Fig.9 and Fig.10 compare the failure pressure under the same conditions in the cylinder and the head position of different corrosion defect geometric parameters. Fig.9 describes when the corrosion defects are in the cylinder body, the effect that the defect length, width and the depth have on the failure pressure. Fig.9 (a) shows that with the increase of corrosion defect length, failure pressure decreases, but the decrease is very small, the defect length increases from 60mm to 260mm when the failure pressure drops less than 0.1Mpa, so the impact that cylinder's corrosion defect's length has on the failure pressure is so small. And under the same defect length and depth condition, influence of cylinder position corrosion defect width has on the failure pressure as is shown in Fig.9 (b) ,we know that with the increase in the width of the corrosion, failure pressure is gradually smaller ; but the corrosion defect's width changes evenly, and failure pressure shows even changes.. Therefore, influence the barrel body corrosion defect width has on the failure pressure doesn't have linear relationship. Under the same defect length and width conditions, the effect that corrosion defect' depth has on failure pressure is shown in Fig.9 (c) shows that with the corrosion depth increasing, separator failure pressure gradually decreases, but the decline also decreases gradually. But compared with the influence of the length and width of corrosion on the failure pressure, the change of the depth of corrosion has more influence on the separator.

When corrosion defect is located in the head, the influence of defects' depth and width on failure pressure of the separator is shown in Fig.10. Fig.10 (a) shows, due to the assumption that the defect is square (length and width are equal), in the same width, with the increase of the defect depth, separator failure pressure changes significantly. And it gradually decreases, the trend is basically linear. And in the same corrosion depth, influence of defects' width on the failure pressure is shown in Fig.10 (b). From Fig.10 (b)

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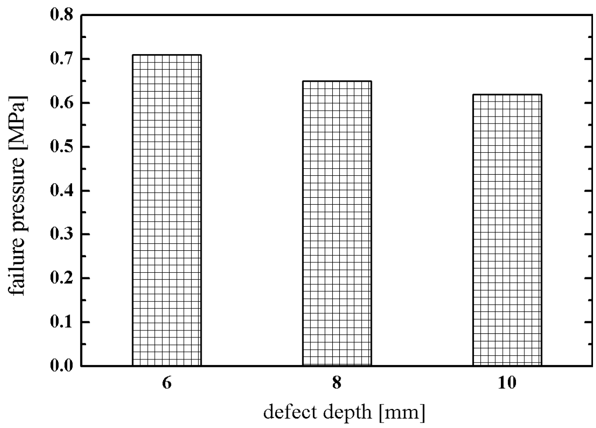
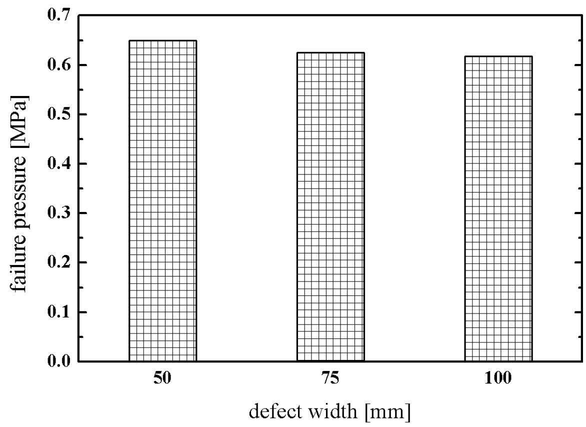
can be seen, with the increase of corrosion defects' width, separator's failure pressure changes slightly. It has very little influence on the width of defect failure pressure. Furthermore, comparing the effect of head position's corrosion defects' depth to that of the width on failure pressure of the separator, effect of defects' depth on failure pressure is greater than the width of defects, and it more easily make cyclone separator invalid.



（a）The influence of depth



（b）The influence of width

Fig.10 The influence of geometric parameters about corrosion defect of head.

Conclusions

The geometry of corrosion defect size under the same condition, the corrosion defect in head position, the maximum equivalent stress of regional corrosion defects in any of the same internal pressure is greater than that in the cylinder corrosion stress region, and when the corrosion defect is located in the head position of corrosion, residual strength of the three-phase separator is more significant so it more easily lead to three-phase separator failure.

When the square corrosion defect is located inside of the cylinder, with corrosion defect length, width and depth increasing, the corresponding failure pressure of the three-phase separator of is smaller and smaller, and it is more likely to fail in advance. The influence of corrosion defect depth on residual strength is greater than the length or width of separator defect on the residual strength of separator.

When square corrosion defect is located inside of head, with increasing cross section width and depth, the three-phase separator's failure pressure is smaller and smaller, and approximately changes linear. In addition, compared to the impact of corrosion defect width, the depth of the head defect has more significant influence on the ultimate bearing capacity of the three-phase separator.

Acknowledgements

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