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Aleksandar Jovanović[1], Branislav Đorđević[2], Lazar Jeremić[2], Simon Sedmak[2], Ana Petrović[3]*

INSPECTION OF DAMAGE AND RISK ANALYSIS OF CONTAINERS IN A COAL DRYING FACILITY IN EXPLOITATION

INSPEKCIJA OŠTEĆENJA I ANALIZA RIZIKA BIDONA U SUŠARI UGLJA U EKSPLOATACIJI

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Adresa autora / Author's address:
1*) Mont R Ltd., Belgrade, Serbia, a.jovanovic@mont-r.rs
2) University of Belgrade, Innovation Centre of the Faculty of Mechanical Engineering, Belgrade, Serbia
3) University of Belgrade, Faculty of Mechanical Engineering, Serbia

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- risk analysis
- damage repair

Ključne reči
- posuda pod pritiskom
- analiza rizika
- reparacija oštećenja

Abstract

Risk analysis of containers in a coal drying facility was performed using the Failure Modes and Effects Analysis (FMEA) method in combination with the risk matrix. The selected exploitation period analysed for all vessels was 5 years, since there is a lot of data about the maintenance performed during this period, including results of material testing performed by an accredited laboratory. Based on all issues detected by testing, risk probabilities (with corresponding levels of severity) of various defects were calculated, and potential expected repair costs determined. These probabilities were then used as input for the risk matrix which indicated the most critical types of defects, both in terms of occurring probability and the severity of their occurrence. It was concluded that through-thickness cracks were the most dangerous defect in this case. Furthermore, high probabilities of most defects considered, implied that containers will become unreliable and unfit for continued exploitation in the near future. Suggested means of preventing failures include a more thorough periodic maintenance and control of these vessels, until it is possible to fully replace them with new equipment.

Izvod

Analiza rizika bidona u sušari uglja je procenjena metodom FMEA (Failure Modes and Effects Analysis), u kombinaciji sa matricom rizika. Analiziran je period eksploatacije od 5 godina, zbog velike količine dostupnih podataka o održavanju tokom ovog perioda, uključujući i rezultate ispitivanja materijala od strane akreditovane laboratorije. Na osnovu svih problema koji su otkriveni ovim ispitivanjima, proračunate su verovatnoće rizika (uz odgovarajuće nivoe opasnosti) za različie greške, nakon čega su određeni potencijalni troškovi reparacije. Ove verovatnoće su potom iskorišćene kao ulazni podaci za matricu rizika, koja je odredila najkritičnije vrste grešaka, kako u smislu verovatnoće njihove pojave tako i u pogledu ozbiljnosti posledica. Zaključeno je da su najopasnije greške prolazne prsline. Štaviše, visoke verovatnoće pojave većine analiziranih grešaka ukazuju na pojavu nepouzdanosti bidona, koja bi ih učinila nepodobnim za dalju eksploataciju, i to u bliskoj budućnosti. Predložene mere sprečavanja otkaza obuhvataju detaljnije periodično održavanje i kontrolu ovih posuda, sve dok ne bude moguća potpuna zamena ove opreme novom.

INTRODUCTION

This paper involves the integrity assessment of containers in a lignite drying facility. The facility in question is the part of Nova Sušara Vreoci (in Serbia). This lignite drying installation was of particular interest for analysis, not only due to aggressive exploitation conditions to which it was subjected /1, 2/, but also due to the poor design of the whole structure itself, which has made the potential replacement of damaged parts extremely complicated. Thus, it was decided to perform a risk assessment of the installation's integrity /3-5/, in order to determine if it could continue working in its current state, or if a repair/replacement of its part is necessary.

Structures like this typically consist of autoclaves connected to pipelines via containers which accumulate wastewater and drying products during the drying process, then to be transported in the form of hot water into autoclaves with raw coal with each new cycle, thus being reintroduced to the drying process. During this stage of the drying cycle, coal is being preheated, and then accumulated in respective containers again. Finally, it is transported to the collecting tanks, /6/.

Drying of raw coal in Nova Sušara facility in Vreoci follows the Fleissner procedure, which includes drying in a saturated water steam atmosphere, /7/. Construction of the drying facility, in accordance with the aforementioned procedure was entrusted to VOEST - ALPINE company from Austria, and it started working during the 1986-1987 period. Taking into account its design capacity of 800.000 tonnes/year and number of work cycles of 126,000 (with one cycle lasting 160 minutes), it was assumed that containers and autoclaves (both being pressure vessels) would have a 40-year working life. First, initially delivered containers were replaced in 2002, due to issues during exploitation. Later, it was estimated that the repair of existing autoclaves is no longer economically justified, and based on this conclusion, it was decided to start with the reconstruction, which took place from 2020 to 2021. This reconstruction included the replacement of middle and lower mantle and its lid for all 16 vessels, along with reinforcing of supports. However, containers remained the subject of periodic repairs and the main cause of downtime during the operating life.

HISTORY OF FAILURES AND RECONSTRUCTIONS

Initial issues with containers are dated to a period after only 3 years of exploitation, i.e., during 1990, when sudden failure occurred, manifested in the form of leakage, and was attributed to the previously mentioned unfavourable design. Technical characteristics of the connecting vessel are shown in Table 1. The specific aspect of these vessels is that their working medium is steam and water condensate from the autoclave, and its chemical composition is characterised by the presence of bicarbonates and increased concentration of SO_4^{-2}, HCO_3^{-1}, and Cl^- ions.

Table 1. Technical characteristics of old containers.

Maximum working pressure	33 bar
Maximum working temperature	250 °C
Test pressure	43 bar
Work medium	water/steam condensate
Volume	26 m^3
Empty vessel mass	10 965 kg
Outer diameter, D_s	2 500 mm
Height	3 920 mm
Mantle wall thickness Lid thickness	26 mm 24 mm
Material	Altherm 55

In order to assess the type and nature of damages that had occurred, extensive non-destructive tests /8-11/ were conducted for all containers, and it was concluded that the damage in question involved thinning of vessel walls in the upper lid and mantle zones, in the immediate vicinity of the lid. Wall thinning in certain regions was greater than 90 % of built-in thickness. Time period over which the damage occurred indicated significant flaws in the design solution for introducing of the condensate into the vessel, which resulted in erosion-corrosion action of the condensate on the impact surfaces of the vessel. The equipment supplier suggested reconstruction of the system for condensate intake and release, by introducing the condensate via 'hat' which ensues uniform draining of the condensate along the connecting vessel walls. Instead of replacing damaged vessels with newly designed ones, the existing vessels were reconstructed, along with the repair of damaged surfaces by replacing the upper lid and part of mantle. Reconstruction and repairs were entirely performed in accordance with the technical documentation provided by the equipment supplier, VOEST - ALPINE.

REPAIRS AND ANALYSIS OF EXISTING VESSELS

Design flaws of the initially delivered containers were largely resolved during reconstruction. A request was made to replace the material of the originally delivered vessels - Altherm 55 with a new material, P355NH, according to EN 10028-3 /12/. Complete replacement of containers was performed in 2002, and the new equipment was manufactured by SES ŽELIEZOVCE, from Slovakia.

Some advantages of the newly selected materials over the original ones are as follows:
- better resistance to surface corrosion,
- better erosion wear resistance,
- better weldability,
- lower sensitivity to stress corrosion during exploitation,
- higher purity (S < 0.01 % and P < 0.015 %).

Considering that a systematic correction of operating parameters for the existing containers was performed in the meantime, these vessels had different operating parameters compared to the originally delivered equipment, and these new parameters are shown in Table 2.

Table 2. Technical characteristics of existing containers.

Maximum working pressure	25 bar
Maximum working temperature	230 °C
Test pressure	33 bar
Work medium	steam/water condensate
Volume	26 m^3
Empty vessel mass	10 965 kg
Outer diameter, Ds	2 500 mm
Height	3 920 mm
Mantle wall thickness Lid thickness	26 mm 24 mm
Material	P355NH

Manhole and flange connection for the condensate discharge pipe were made of material WSTE 355, according to DI 17102-84, as forgings. Wall thicknesses was 30 mm for all forgings in the area where welding was performed. With this, the requirements were met for avoiding fillet welds at pipe connections, and it was possible to butt-weld the connectors to the vessel mantle. The lid and its elements were made of high-alloyed acid-resistant steel, X5CrNiMo 18-10, according to EN 10088, /13/.

DAMAGES OF EXISTING CONTAINERS

Aforementioned damages that occurred in the containers during exploitation were detected and monitored using modern non-destructive test methods. Some of the most commonly encountered types of damage are shown in Fig. 1, wherein one of the most critical damage types, which will be considered by the risk analysis shown here – the vessel mantle wall thinning, can be clearly seen.

a)

b) 

Figure 1. Most common damages in containers: a) wall thinning in the upper mantle and lid; b) cracks in the shower connector areas.

The established procedure for the removal of defects shown above involves repair welding / surface welding which will not be considered here in detail, but its application is shown in Fig. 2.

Figure 2. Repair welding of connecting vessel mantle thinned walls.

FMEA AND RISK MATRIX APPLICATION

In order to improve the existing conditions and to focus on key systematic problems related to design and its implementation, this research focuses on analysing the nature and consequences of failure via the method known as Failure Modes and Effects Analysis (FMEA). The goal here is to relate traditional FMEA /14/, a post-engineering activity mainly applied during the development of projects involving real pressure vessels - such as containers with risk analysis. For the purpose of figuring out the best solution for the improvement of existing container functionality, the exploitation of all 16 vessels over the past five years was analysed. The selected exploitation period is specific in the sense that vessel maintenance during this period was performed by a subcontractor monitored by the accredited laboratory for material testing and a notified body for pressure equipment, thus the obtained data are relevant for further analysis. During a 5 year period, legal regulations for internal inspection require that it is performed every 2 years, which suggests that every connecting vessel was inspected/repaired no more than twice according to the relevant procedure. During this period, all key flaws which affected the performance of containers, as well as the installation as a whole, were detected and classified. Quantitative and qualitative values of observed flaws are given in Table 3.

Taking into account that a total of 6, out of 8 listed potential risks were detected, and that all of them could potantially lead to failure of the ‘vertical’ made of the autoclave and containers, while also resulting in downtime, these defects were considered in the analysis presented here. One of the most common results obtained by applying FMEA is the so-called RPN - Risk Priority Number /14/, and it represents the mathematical product of failure consequence severity (denoted as S), probability of failure occurrence (O), and failure detectability value (D):

$$RPN = S \times O \times D.$$

Table 3. Classification of flaws in the existing containers.

Type of observed flaw	Number of flaws
Upper lid wall thinning	13
Upper mantle wall thinning	26
Lower mantle wall thinning	0
Lower lid wall thinning	0
Cracks in the shower connector area	18
Cracks in the longitudinal welded joints	5
Fatigue cracks in the mantle	3
Through-thickness cracks	2

Three values mentioned above do not have the same weight when compared in terms of risk. High RPN value indicates the severity of a certain form of failure, especially when coupled with high probability of occurrence. A comparative review of expected costs and RPNs for 6 different types of failure from Table 3 is shown in Table 4.

As can be seen, Table 4 provides the comparison of RPNs for different failure scenarios, wherein the probability of occurrence (O), severity (S), and detectability (D), are adopted according to AIAG recommendations, /15/. Based on these parameters, Risk Priority Numbers are determined and are shown as a function of failure type in Fig. 3, along with expected costs. As expected, the highest risks, i.e., RPNs were observed in failure types related to cracks, which are the most common causes of failure in pressure vessels.

In addition to applying FMEA to connecting vessel risk analysis, the said vessels will be also analysed using the risk matrix /3, 4, 16-20/, in order to perform a parallel comparison of these two risk analysis tools.

In order to obtain the risk levels for containers via risk matrix, the previously shown FMEA results, i.e., listed types of failures will be used as the base, as seen in Table 5.

Table 4. Comparative review of expected costs and RPNs.

Failure type	Probability of occurrence (per vessel)	Expected costs (€/vessel)	Total expected costs (€)	O	S	D	RPN
Upper lid wall thinning (A)	0.19	6.809	1.321	6	6	4	144
Upper mantle wall thinning (B)	0.39	34.043	13.211	6	10	4	240
Cracks in the shower connector area (C)	0.27	1.702	457	8	8	4	256
Cracks in the longitudinal welded joints (D)	0.07	2.383	178	8	6	4	192
Fatigue cracks in the mantle (E)	0.04	3.404	152	8	6	6	288
Through-thickness cracks (F)	0.03	6.809	203	10	6	9	540

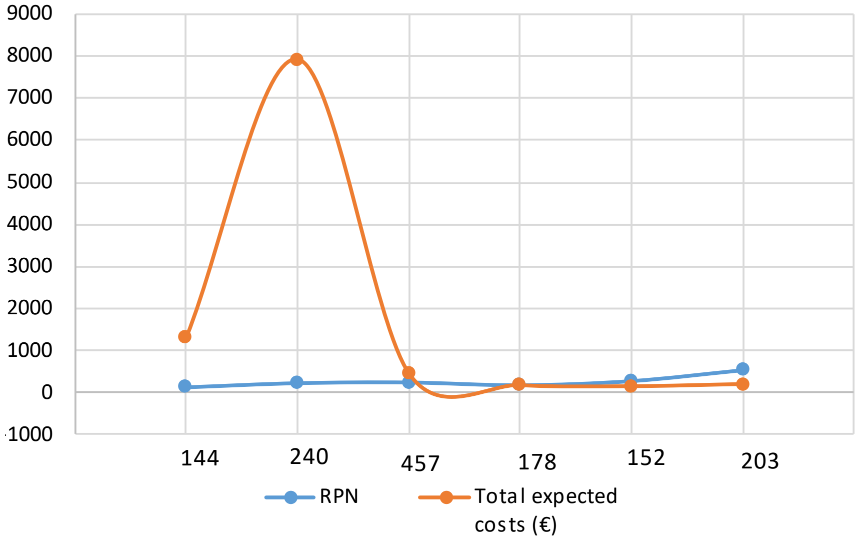

FIgure 3. Comparative display of RPNs and expected costs.

Table 4. Risk matrix of flaws in existing containers.

		Consequence category					
		1 – very low	2 - low	3 - medium	4 - high	5 - very high	Risk level
Probability category	≤ 0.2 very low						Very low
	0.2-0.4 low						Low
	0.4-0.6 medium			Upper lid wall thinning (A)	Cracks in longitudinal welded joints (D)	Upper mantle wall thinning (B)	Medium
	0.6-0.8 high				Cracks in the shower connector area (C)	Fatigue cracks (E)	High
	0.8-1.0 very high					Through-thickness cracks (F)	Very high

CONCLUSIONS

Engineering tools such as FMEA and the risk matrix are among the most commonly used means of modern analysis of failure in order to determine the level of danger and expected costs which could result from the said failures. Based on everything presented here, it can be concluded that containers have very high risk levels. The highest risks are related to through-thickness cracks which are not the currently dominant failure mechanism, but could become one if other causes of failure, such as wall thinning and fatigue cracks in welded joints, are incompletely repaired. In this case, too many repairs could eventually lead to the occurrence of through-thickness cracks, thus compromising the reliability and safety of the pressure equipment which is already at high risk levels (category IV according to the risk matrix). Should such a scenario occur, the installation needs to be shut down in order to prevent fatal accidents.

To achieve the above goal, it is necessary to continue with regular, periodical testing and control of containers, in accordance with measures provided by relevant standards. In this way, the coal drying installation can continue operations up to a point where urgent replacement of equipment with new parts can no longer be avoided, and risk assessment methodologies used in this research can provide valuable insight about the more or less exact moment when this replacement will be necessary.

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Important dates
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Contact information
For any info, please, do not hesitate to contact:
Email: lucas@fe.up.pt