REMAINING WORKING RELIABILITY OF VERTICAL FIRED HEATER WITH SIMULTANEOUSLY USED RBI MATRIX

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Abstract: *This paper deals with the reliability of a vertical gas heater installed in an oil and gas plant, which has been in continuous operation for an extended period. It provides a classification of fired heaters based on their construction characteristics, and outlines their role within the gas rectification process, including the types of equipment involved. The general construction of the heater is described, along with key design and operational process parameters. The paper also identifies damage mechanisms that affect this type of equipment. A Risk-Based Inspection (RBI) analysis was conducted, and an RBI matrix was developed, indicating that the equipment falls into the high-risk category in terms of both financial consequences and environmental impact.*

Key words: *Gas heater, creeping, rectification, RBI*

Introduction

The paper explains the main phases of gas rectification in one upstream desert plant [1]. Since entering feed into the plant it passes through phases of rough purification which consist of slug catchers for removing sand and slugs. After that raw gas passes through filters before entering the compressor unit where it takes place of pressure increasing for the needs of providing appropriate process parameters for further gas purification. Within the next stage, the feed to the gas dehydration unit is the treated gas in the Gas Sweetening Unit saturated with water. The gas from the Gas Sweetening Unit is sent to the gas/gas exchanger where it is cooled down by heat exchange with the rectified gas from the Cold Box installed in the Dew point control unit. Downstream of the exchanger, the mixed dryers inlet separators are designed to achieve 3-phase separation. This dryer generally belongs to a drum type of pressure vessel which is vertically installed and equipped with one even-flow type inlet distributor and one internal heavy-duty mesh. The decanted water is further routed to the waste water treatment unit under interface level control. The separated hydrocarbon phase is sent to the inlet separator to another unit for further purification.

Also, a draw-off line with a manual valve is provided at the drum bottom part to perform skimming of hydrocarbon/amine emulsions from the decanted water. The emulsions will be sent either to the appropriate skimming pot or directly routed to the following amine recovery drum however, both items are parts of the Gas Unit Sweetening facilities. The drum overhead gas stream is sent to the inlet dryers coalescer where a higher degree of liquid separation takes place to reduce any liquid carryover to molecular sieves beds in the next gas dryers. The coalescer features a two-compartment design. The bottom compartment acts as a KO drum and, is designed for this purpose. Gas from the bottom compartment feeds the top compartment through the vertical coalescing elements. The liquid collected from the coalescing elements is removed from the drum to a side liquid pipe receiver and routed in another oil unit for further purification.

The gas from the inlet dryer coalesce is then routed to the molecular sieves beds of the next three gas dryers in which moisture content is reduced below 0.1 ppmv. The gas flows downwards through two parallel dryers while the third dryers while the third dryer is reactivated. Dry gas exits the bottom of two dryers and flows to the dry gas filter to remove any molecular sieve powders in the dry gas. Dry gas from dry gas filter is sent to the appropriate dew point control unit. A silica or alumina gel layer is installed on top of the beds, to increase the integrity of the molecular sieves beds.

Further gas rectification takes place after being withdrawn from the dry gas filter outlet. Gas dried in the previously mentioned manner is sent to the appropriate Gas separator where hydrocarbon condensation that appeared by pressure loss through the appropriate flow valve is collected and routed to the oil unit for further purification. On the other side overhead gas from the Gas separator is sent to the Fired heater. Finally, in fired heater which is practically one regeneration unit takes the place of heating of gas by the heat obtained by three burners attached to the bottom of the heater. Gas is heated in the vertical pipes in the radiation zone and after that in the convection zone and it is sent to the Dryer in a regeneration sequence to remove water from the molecular sieve. The heat obtained by the burners is very high and it affects the tube wall during a long time operation period.

Many previous researches were devoted to improving energy efficiency and construction and design. The most accepted standard for the design of fired heaters is API 560 [2]. Mostafavi and Rezaei [3] found that increasing the speed of the burning gas reduces fuel consumption. Karem et al. [4] confirmed that increasing the furnace outlet upstream stream flow rate and decreasing the heat loss fraction through the refractory wall, pip doors, expansion windows and refractory hair cracks would also increase the efficiency. Yantumi et al. [5] presented a dynamic mathematical model of an existing fired heater incorporating partial differential-algebraic equations for predicting the HTF supply temperature, Hajek and Jegla [6] reported new data and quantified corrections of two dominant heat flux variation factors that are based on numerical modelling, large-scale laboratory measurements and real-life data from the operating fired heater. Elsaid et al. [7] created a computer-based program that can monitor and calculate the average TMT, based on Lobo–Evan equation and applied it to different cases. Hajek et al. [8] numerically simulated the radiant section of a fired heater. They focused on the tube-wall distance and investigated the effect that the tube-wall distance has on the distribution of heat flux on tube walls. Ahanj et al. [9] used the DTRM modelling of radiation heat transfer and experimentally studied combustion from radiant tube heaters. Parnian [10] investigated the failure of stainless steel tubes in a fired heater caused by NaOH.

Fuentes et al. [11, 12] investigated operating conditions on fouling rates in fired heaters. such as the number of tubes, number of shield tubes, number of passes and number of tubes per pass in the fired heaters. Mussati et al. [13] presented a mathematical model for the optimization of some geometric design parameters. Much research was devoted to Overheating and corrosion e in tubes of fired heaters [14–18]. Farrahi et al [19] investigated the sources of failure in fired heaters, such as high temperature, flame concentration, high thermal stress and so on. Morales-Fuentes et al. [20] analyzed the crude side of a vertical fired heater and evaluated the impact of process conditions such as throughput and crude inlet temperature (CIT) on the fouling that takes place at the early stages of operation. Jegla et al. [21] analyzed heat transfer in a model-fired heater using classical design calculation methodology according to API and a CFD model with the application of adequate models for turbulence, combustion chemistry and radiation. Erfan et al. [22] presented the results of a numerical modeling of a fired heater in a refinery. Haratian et al. [23], optimized the design of process-fired heaters using a mathematical model associated with genetic algorithms (GAs). Masoumi and Izakmehri [24] calculated that by using combustion air preheating and excess air control, the furnace efficiency of a refinery can be improved by about 26%. Al-Haj Ibrahim and Al-Qassim [25] simulated and analyzed the heat transfer mechanisms inside the process-fired heaters. Chaibakhsh et al. [26] investigated the thermal performance of a heater in Matlab simulink environment.

Taking into consideration the fact that Gas Heaters are process equipment which pulls off the roots of their constructions at the beginning 20th century (more correctly 1903 year) problems related to their damage during operating life and RBI methodology up to nowadays have not been sufficiently explored, hence and it is the main goals of this paper is an analysis of their working reliability and methodology of preforming of RBI matrix [27-29].

Technical data of the fired heater

The cylindrical heater with vertical tube coil is presented in Figure 1.

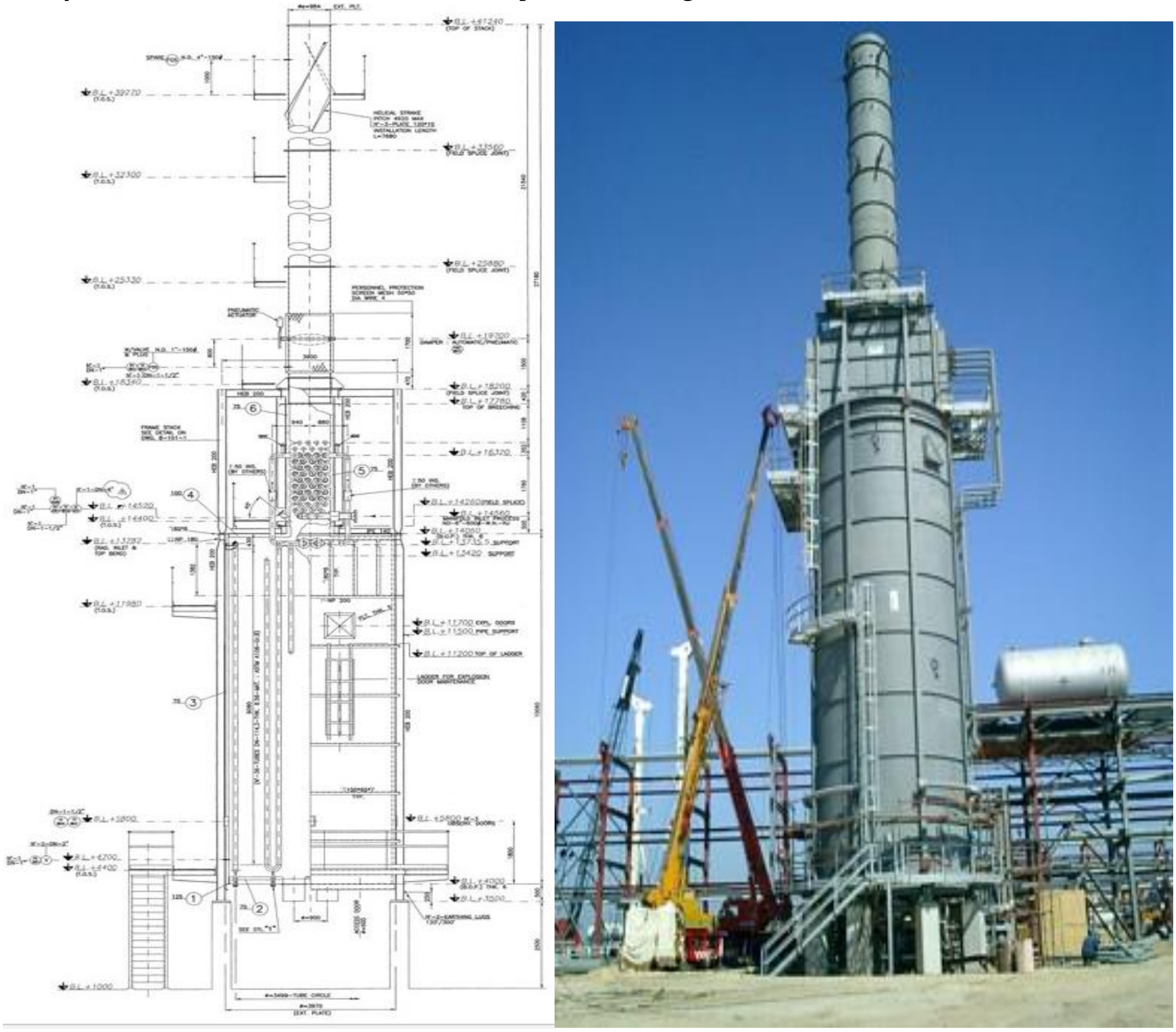

Figure 1. Cylindrical heater with vertical coil technical drawing and view during turnaround

Generally viewed, interior of this process apparatus can be divided into two main zones. Vertically pipes are installed in the lower part of the apparatus which is belonging to the first zone and which is usually named radial zone of the apparatus and these pipes are directly affected by the flame which is comes from the burners. These vertically pipes are installed in a circular manner in the interior side of cylindrical shell.

These pipes on their upper part are supported on the fixed pipe supports while on their bottom parts, they have additional, which are entering in the holes in the floor (which act such as movable supports). Like this structural solution enables thermal expansion of these vertical pipes in the apparatus during normal working operations that is, with what is avoiding their distortions and cracks due their exposed on the higher working temperatures (Figure 2 and Figure 3).

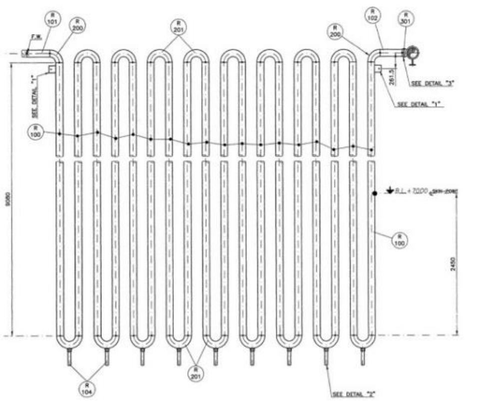

Figure 2. Vertical pipes in fired heater-detail 1-fixed supports, detail-2-movebale supports

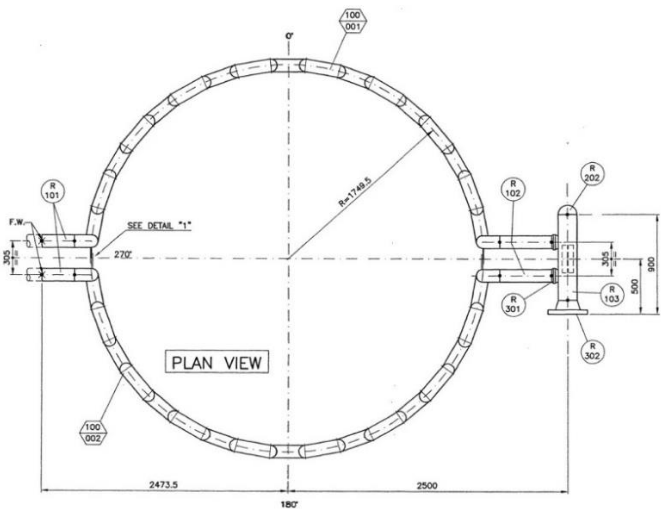

Figure 3. Schedule of the vertical pipes in cylindrical fired heater-plan view

On the other side package of horizontal pipes, which have installed above the previously mentioned vertical pipes is belonging to the second zone of the apparatus. Usually, this zone of the apparatus is calling convection zone because the impact of the flame on this package of pipes is usually very low and heat transfer mechanism is take place usually like as convection heat transfer. In addition, here should be highlight that the all tubes in the radial zone are the smooth tubes while some of the tubes in the horizontal tube package in convection zone are finned with transverse fins for needs of increasing heat transfer intensity. Detail view of the horizontal tube package has presented on the Figure 4 and Figure 5.

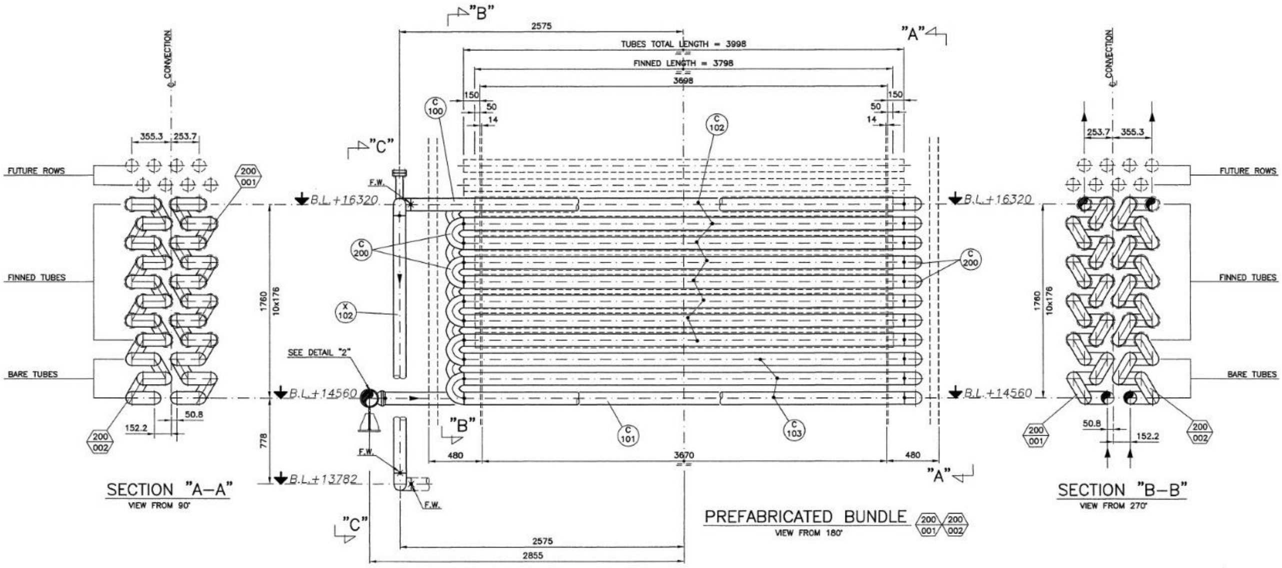

Figure 4. Package of horizontal tubes in the convection zones of the heater

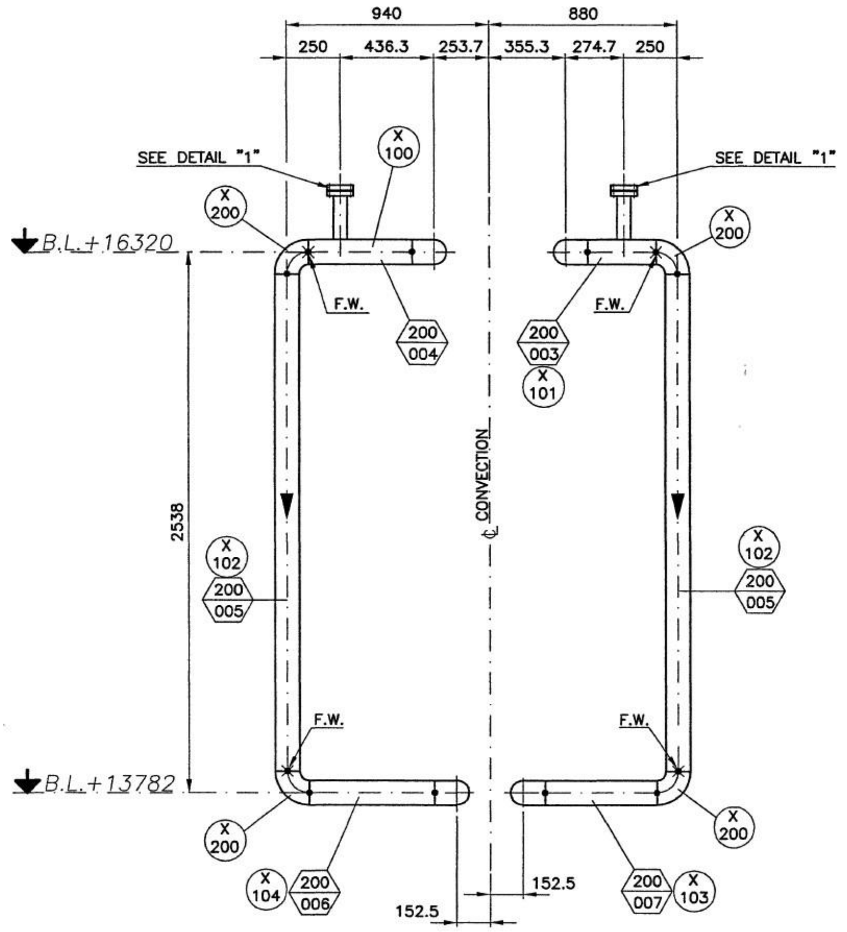

Figure 5. Package of horizontal tubes in the convection zones of the heater

Design parameters such as and the main materials in the apparatus has presented in the table 1 and table 2 below.

Table 1. Design parameters and main materials of the apparatus in the radiation zone

No	Design data	Value	Unit	Remarks
1	Design temperature	430	˚C	
2	Design pressure	6800	kPa(g)	
3	Hydrostatic pressure	15300	kPa(g)	
4	Corrosion allowance	3.00	mm	
5	X-ray (butt-weld)	20	%	
6	Dye penetrant	10	%	
7	Post weld heat treatment	NA	%	Due low thickness
8	Magnetic particle examination	10	%	

Tubes in radiation zone				
No	**Quantity**	**Description/material**	**Length(mm)**	**Remarks**
9	36	R100-ND-4”-Sch80-pipe/ A106-Gr.B	9080	
10	2	R101-ND-4”-Sch80-pipe/ A106-Gr.B	630	50 mm-extra length
11	2	R102-ND-4”-Sch80-pipe/ A106-Gr.B	458	
12	1	R103-ND-6”-Sch80-pipe/ A106-Gr.B	775	
13	18	R104-ND-1-1/2”-Sch80-pipe/ ANSI310	244	

Tube fittings in the radiation zone of apparatus				
No	**Quantity**	**Description/Schedule**	**Material**	**Remarks**
14	4	R200- 90˚-Return bend L.R. ND4”-Sch80	ASTMA234-WPB	
15	34	R200- 180˚-Return bend L.R. ND4”-Sch80	ASTMA234-WPB	
16	1	R202-Cap L.R.-ND6”-Sch80	ASTMA234-WPB	

Table 2. Design parameters and main materials of the apparatus in the convection zone

No	Design data	Value	Unit	Remarks
1	Design temperature	430	˚C	
2	Design pressure	6800	kPa(g)	
3	Hydrostatic pressure	15300	kPa(g)	
4	Corrosion allowance	3.00	mm	
5	X-ray (butt-weld)	20	%	
6	Dye penetrant	10	%	
7	Post weld heat treatment	NA	%	Due low thickness
8	Magnetic particle examination	10	%	

Tubes in the convection zone				
No	**Quantity**	**Description/material**	**Length(mm)**	**Remarks**
9	2	C100-ND-4”-Sch80-pipe/ A106-Gr.B	4523	50 mm-extra length-finned
10	2	C101-ND-4”-Sch80-pipe/ A106-Gr.B	4707	
11	30	C102-ND-4”-Sch80-pipe/ A106-Gr.B	3998	finned
12	10	C103-ND-4”-Sch80-pipe/ A106-Gr.B	3998	
13	1	C104-ND-6”-Sch80-pipe/ A106-Gr.B	1155	
14	1	X100-ND-4”-Sch80-pipe/ A106-Gr.B	533	50 mm-extra length
15	1	X101-ND-4”-Sch80-pipe/ A106-Gr.B	372	50 mm-extra length
16	2	X102-ND-4”-Sch80-pipe/ A106-Gr.B	2385	50 mm-extra length

17	1	X103-ND-4”-Sch80-pipe/ A106-Gr.B	525	
18	1	X104-ND-6”-Sch80-pipe/ A106-Gr.B	625	

Extended surface-Solid fine						
-	Number of fins	Fin thickness	Fin height	Finned length	Fin material	Max temperature ˚C
19	118.1	1.30 mm	13.0 mm	3798 mm	Carbon steel	200

No	**Quantity**	**Description/Schedule**	**Material**	**Remarks**
19	42	C200-180˚-Return bend S.R. ND4”-Sch80	ASTMA234-WPB	
20	1	C201- 180˚-Cap ND6”-Sch80	ASTMA234-WPB	
21	8	X200-180˚-Return bend S.R. ND4”-Sch80	ASTMA234-WPB	

Damage mechanisms which are affecting process equipment

A *damage mechanism* is a term used to describe any mechanical or chemical process that leads to the deterioration of equipment or materials. These mechanisms can include corrosion, cracking, heat damage, and various other forms of degradation. When assessing damage mechanisms, it is essential to consider not only the current condition of the equipment but also the potential for future damage. The likelihood that equipment will be affected by a particular damage mechanism depends on a range of factors, such as the materials used in construction, the characteristics of the process fluids, operating conditions, and the surrounding environment.

According to widely accepted industry standards, such as API 571 [30], damage mechanisms are typically classified into several categories. These include mechanical or metallurgical failures, uniform or localized loss of material thickness, high-temperature corrosion, environment-assisted cracking, and other less common forms of failure. Understanding the full range of possible damage mechanisms is fundamental to any effective mechanical integrity or reliability program.

A thorough review of potential damage mechanisms plays a key role in developing an appropriate inspection strategy. Once the nature and morphology of the damage are understood, inspectors can select methods that offer the highest probability of detecting, evaluating, and quantifying that damage. Moreover, inspection intervals can be defined using industry codes and best practices. Standards such as API 510 [31] for pressure vessels, API 560[32] for fired heaters, API 570 [33] for piping systems, API 573 [34] for heat exchangers, and API 653 [35] for storage tanks provide guidance on appropriate inspection approaches. For fitness-for-service assessments and risk-based inspection planning, API RP 579 [36], API 580 [37], and API 581 [38] offer additional frameworks that ensure inspections are both effective and aligned with actual risk.

Analysis of operating life of vertical fired heaters

Analysis of operating life of process equipment generally view including: analysis of the design parameters, working conditions, information obtained during regular periodical inspection and materials of metal elements from which appropriate process equipment has fabricated. In this article will be analysed operating life of one vertical fired heater which is installed in the Oil and Gas plant and which is in long time service. During planned turnaround it was performed detail visual examination of the external and internal elements of the vertical fired heater and conducting ultrasonic thicknesses testing of the tubes in the radiation zone such and penetrant testing of the relevant weld joints. Here should be highlight that before removing the equipment from continual service for needs of its examination and before starting inspection activities it was performed analysed available documentation and following of the relevant process parameters in control room such as and their comparing with previously mentioned documentation and information related to the properties of the materials from which this equipment has been built and all in the goal of establishing relevant damage mechanisms, which can be expected (observed) during performing inspection activities. During performing external inspection of the equipment, it was observed circular weld cracks at the both thermocouple nozzles at the connection of thermocouple nozzle and shell of the heater and further analysis it has shown that these were cracks are consequence different material which are connected by welding. Namely thermocouple nozzles are made from stainless steel while the shell of the material is made from carbon steel and due long time working on higher temperature due different coefficient of thermal expansion of these material circular cracks were formed. Also, in sense of providing, more information regarding dimensions of the cracks penetrant tests were conducted which had shown their exact dimensions. After that, it was performed detail cleaning of damaged weld metal up to the sound metal by grinding process. For needs of remediation, mentioned weld defects it was used approved WPS and supported by appropriate PQR. Hence, because base metal of equipment shell is carbon steel and thermocouple nozzle were made from stainless steel for repairing activities it was used electrode E309L-16 with diameter 2.60 mm. For needs avoid possible hydrogen cracks after welding process electrodes were exposed to drying process on temperature 350 ˚C in duration of 1hour. On that occasion, it was used currency of direct polarity with the next parameters: Amperage range 90-110 A, voltage range 20-24 V. Travel speed range during performing repairing activities was in the range 68 mm/min. After finishing repairing activities detail visual inspection of repaired weld joints were performed while taking into consideration that weld joints, which are connecting dissimilar materials, are prone to delayed cracking, penetrant tests were performed 24 hours after finishing repair welding activities in sense of finding potential delayed cracks (Figure 6 and Figure 7).

Figure 6. Visually observed cracks at thermocouple nozzles and penetrant tests after repairing

During external examination of the vertical fired heater, also it was checked status of finned tubes in convection zone (Figure 7).

Figure 7. Finned tubes in convection zone of fired heater

As can be seen from the Figure 7 all finned tubes have found in good condition in time of examination and fins have found in straight positions also places which have planned for the future tubes installation were found properly plugged.

Within of internal examination it was performed detail visual inspection of the main internal elements, such as: refractory, cylindrical burners, which have installed in triangle schedule in the refractory, holes in the refractory which has function of moveable tube support, vertical tubes and appropriate tube fittings installed in the radiation zone of heater, thermoskin couples, available tubes in package of horizontal tubes which have installed in convection zone of the apparatus, fixed tube supports, bolts, nuts, etc… On that occasion, refractory (on the bottom) around burners has found damaged (with some cracks in refractory material) on some places but still in satisfactory condition and its repairing or changing will be conducted within the next planned shutdown (Figure 8).

Figure 8. Refractory and burners of fired heater

During visual examination of fixed supports for vertical tubes, longitudinal crack has observed. Existing of crack was also confirmed with penetrant test of this area.

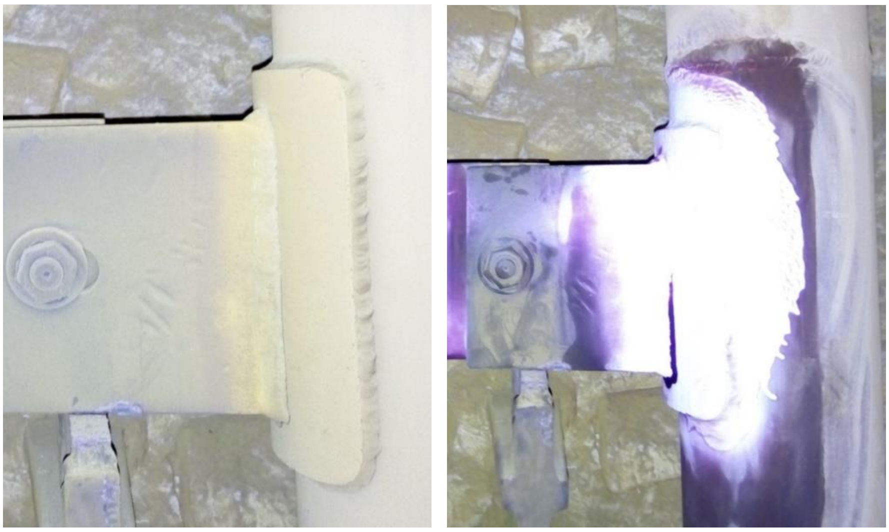

Figure 9. Crack was observed at fixed support for vertical tubes and confirmed with dye penetrants

After that crack was successfully removed by grinding and tube-support was repaired by welding. Repaired weld joint was tested with penetrant test and it has shown that reparation was conducted in successful manner.

Figure 10. Repairing of the cracked support has performed in successful manner

Together with inspection of fixed tube supports of the vertical tubes, detail visual inspection of down moveable tubes supports were performed. On that occasion, also, it was conducted measured of minimum free dilatation lengths and they were compared with maximum dilatation for this material (Figure 11).

Figure 11. Visual inspection of the moveable tubes supports at entering tube part in refractory hole

L=9080 mm, Material-CS-ASTM-A106 Grade, T=430°C, $A = 14.1 \cdot 10^{-6}$ mm/mm/°C

$$\Delta t = t_{design} - t_{atm} = 430 - 20 = 410 \text{ °C} \quad (1)$$

$$\Delta l = A \cdot L_o \cdot \Delta t = 14.1 \cdot 10^{-6} \cdot 9080 \cdot 410 \approx 52.49 \text{ mm} \quad (2)$$

l_{min}=100 mm, in general case Δl should be<l_{min}, 52.49 mm<100 mm so this condition is fulfilled.

This part of inspection also included checking of moving down part of tubes in the holes in the refractory in sense of checking possibilities of dilatation of the vertical tubes during operation period and avoiding distorting and cracking these tubes. Here should be highlight that at some tubes have observed difficult moving of down part of the vertical tubes (R-104-positions) due accumulation sand and dust in the refractory holes.

Inspection of internal tubes has included visual examination of available tubes installed in horizontal tube package in the convection zone and vertical tubes, which have installed in radiation zone of apparatus (Figure 12 and Figure 13).

Figure 12. View of horizontal tubes in the convection zone and vertical tubes in radiation zone

Figure 13. View on the vertical tubes in the radiation zone in the apparatus

Penetrant test of the weld joints at connection of vertical tubes with elbows also performed and cracks have not observed in time of examination (Figure 14).

Figure 14. Penetrant tests of the weld joints of the vertical tubes in radiation zone

Further examination of apparatus status has included of performing ultrasonic thickness measuring of the vertical tubes in the radiation zone for needs of evaluation remaining life of apparatus. Scheme of ut-measuring has shown on the Figure 15 while review of the measured values has presented in the table 3.

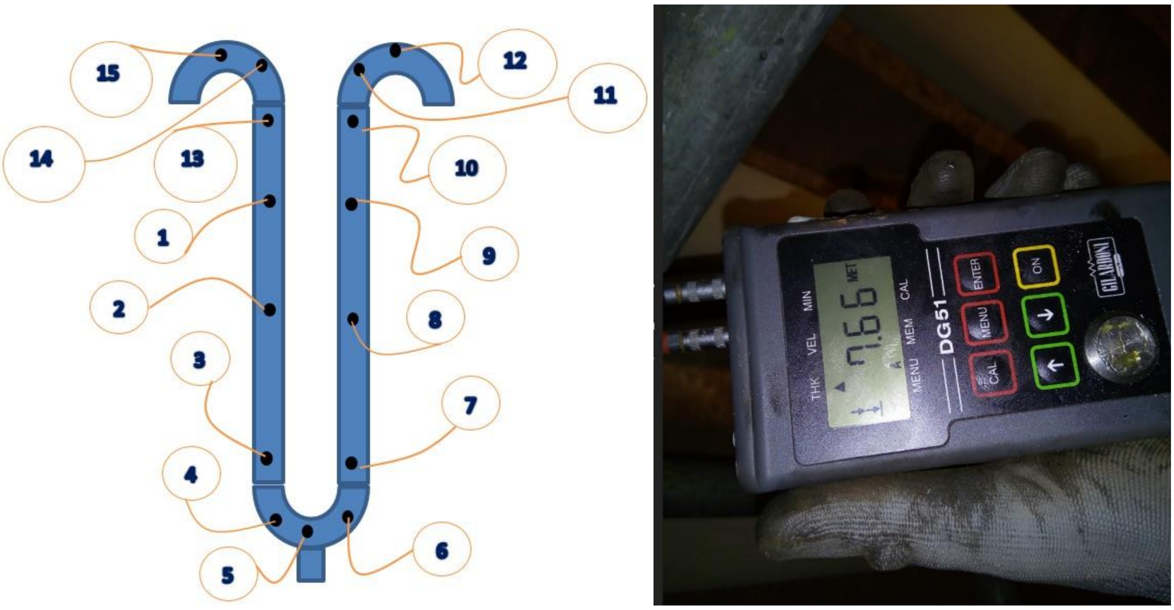

Figure 15. Scheme of ut measuring at vertical tubes installed in radiation zone of apparatus

Table 3. Review of measured values of thicknesses at vertical tubes

Number of tubes (Wall thickness in mm)-Nominal thickness for the tubes is 8.56 mm					
Position/No of tube	**1**	**3**	**6**	**11**	**13**
1	8.8	8.6	8.7	7.0	8.8
2	9.0	8.8	8.8	9.5	8.8
3	9.0	8.9	9.1	9.3	8.5
4	9.0	9.2	8.9	9.0	8.7
5	9.0	8.9	8.4	8.3	9.8

6	9.2	9.0	9.1	8.0	8.1
7	8.5	8.4	9.1	8.3	8.1
8	8.9	8.8	8.9	7.9	8.9
9	8.7	8.8	8.6	8.4	8.1
10	8.9	8.5	9.0	8.6	8.8
11	8.7	8.9	9.5	9.4	8.2
12	9.7	9.0	9.5	9.1	7.8
13	8.4	9.4	8.8	8.2	8.7
14	8.6	9.1	8.7	7.6	8.9
15	8.5	9.3	9.2	8.9	9.0

According to the measured values of thicknesses on the vertical tubes, which has installed in the radiation zone it, was conducting calculation of residual working life of the apparatus.

P=6800 kPa(g)=986.26psig Ca=3.00 mm

ND=4''-Sch80$D_{outside}$=4.5 inch

Material: A106 Grade B, so value of allowable stress is: S=11300 psi

Minimum required thickness calculated according to the formula from ASME B31.3 will be:

$$t_{req} = \frac{p \cdot D}{2(S \cdot E + pY)} \quad \text{in inch or mm} \tag{3}$$

$$t_{req} = \frac{p \cdot D}{2(S \cdot E + pY)} = \frac{986.26 \cdot 4.50}{2\left(11300 \cdot 1 + 986.26 \cdot 0.4\right)} = \frac{4438.17}{2 \cdot 11694.54} = \frac{4438.17}{23389.00} = 0.1898 \text{ inch=4.82 mm} \tag{4}$$

Taking into account the fact that previously measuring of thicknesses was not performed in this case only corrosion rate (long time) can be calculated. Corrosion rate has calculated according [10],[11]:

$$CR(LT) = \frac{t_{initial} - t_{\min}}{\text{time between them}} \tag{5}$$

Calculated corrosion rate (long time) for the vertical tube (tube marked with 11 and position marked with 1 according to the Figure 13) will be:

$$CR(LT) = \frac{8.56 - 7.0}{13.50} = 0.1156 \text{ mm/year} \tag{6}$$

On the other side calculated corrosion rate (long time) for the elbow (which has attached to the tube marked with 11 and position marked with 14) will be:

$$CR(LT) = \frac{8.56 - 7.66}{13.50} = 0.0667 \text{ mm/year} \tag{7}$$

After comparison of calculated corrosion rates for vertical tube and for elbow for further analysis will be adopted higher values between these two values hence relevant corrosion rate is 0.1156 mm/year. Here should be highlighted that this position is belong top of the tube elbow and that decreasing of the thickness is the most probably consequence of simultaneously effects of erosion and corrosion this this fitting. Calculation of Remaining life of the apparatus in general case will be performed by using the following formula

Number of working hours (NWH) which apparatus has spent in service: NWH=84300 hours;

Design temperature of apparatus: 430˚C

Material of tubes: CS-ASTM-A106-Grade B

Border temperature for creeping for material CS-ASTM-A106-Grade B=345˚C

So according to the previously mention it can be concluded that mentioned heater is working in creeping working regime. For needs of additional confirmation values of measured temperatures from thermocouples have took from plant control room and they used for deeper analysis of behaviour of fired heater in working period (Figure 16).

Figure 16. Values of temperatures on the vertical tubes in radiation zone

As can be seen from the Figure 16 values of temperatures in some moments have reached temperature around 700˚C according from it can be concluded that vertical tubes have operated in deep creeping regime. Taking into account this fact maximum free dilatation for the vertical tubes will be: L=9080 mm, Material-CS-ASTM-A106 Grade, T=700°C, $\mathrm{A} = 18.0 \cdot 10^{-6}$ mm/mm/°C

$$\Delta t = t_{design} - t_{atm} = 700 - 20 = 680\ °\mathrm{C} \quad (8)$$

$$\Delta l = \mathrm{A} \cdot L_o \cdot \Delta t = 18.0 \cdot 10^{-6} \cdot 9080 \cdot 680 \approx 111.14\ \mathrm{mm} \quad (9)$$

According to this it can be concluded that low distortion of the tubes have started. Observed temperature (that is their amplitudes) are consequence of uneven work (and non settings) of the bottom burners. Like this type of behaviour of flames on the vertical tubes in some cases producing distortion of tubes and in the borderline case even a cracking of the tubes due even thermal expansion of side of the tube, which has directly exposed to the flame, and the other side of the tube. During performed visual examination of this fired heater, this effect luckily has not observed. Together with this and based on the information regarding of number of working hours can be concluded that metallographic examination should be performed after next 15000 working hours.

RBI analysis

Risk-based inspection is a powerful tool for identifying and managing mechanical integrity risks in fixed equipment and pipelines, but it has some drawbacks that can lead to costly reliability problems or unjustified maintenance costs.RBI does not include cases where failures have process consequences, but not mechanical integrity problems, such as pipe-in-sheath leaks.–According to API 581 [27] there are two approaches to

determining the Probability of failure for heaters. Both approaches to determining PoF have their advantages and disadvantages. PoFw includes the Weilbull parameter and is more suitable for use when doing RBI analysis to determine the basic inspection, while PoFg includes the generic failure frequency (gff) and the determination requires more complex data, i.e. there must be an adequate history of inspection, design and operation of the heat exchanger, content of service fluids in the pipeline, as well as the issue of safety management at your facility. PoFw determination is very useful when considering the potential failure rate of the mechanism.
RBI is calculated according to API 581 [27] as product of a probability of failure (POF) and the consequence of failure (COF) presented by the following equitation:

$$R(t) = P(t) * C(t) \tag{10}$$

In this paper, the risk is calculated according to PoFw [27]:

$$PoF_w = 1 - exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \tag{11}$$

where:
t- time, years
η- is the Weibull characteristic life parameter, years
β- is the Weibull shape parameter.

The Weibull characteristic life parameter is calculated according [27]:

$$\eta = \frac{\mathrm{MTTF}}{\Gamma\left(1+\frac{1}{\beta}\right)} \tag{12}$$

According to API 581 if PoF is calculated using MTTF, β is known, i.e. default 3.
MTTF is the mean time to failure and is calculated as follow [27]:

$$MTTF = \frac{1}{FR_{tube}} \tag{13}$$

Where FR_{tube} is failure rate per year and is derived from the equitation:

$$FR_{tube} = \frac{meanfailurerate}{10^6} x8760\ hours \tag{14}$$

Finally, mean failure rate is taken from OREDA – Offshore and onshore reliability data [29]. OREDA contains data related to failure frequency and failure rate for various process equipment used in the offshore and onshore oil and gas industry. Table 4 gives values of mean failure rates for specific failure models that can occur in the analyzed heater.

Table4. Mean failure rate for specific failure models

Failure modes	Mean failure rate (10^6 hours)
External leakage - Process medium	2.03
Insufficient heat transfer	0.34
Internal leakage	2.03
Minor in service problems	2.03
Overheating	0.68
Total	7.11

For the given values:
FRtube= 0.063120 peryear
MTTF=15.93333
η=16.939
PoF=0.73521

Consequence of failure is determined based on the following equation [29]:

$$C_f^{tube} = Cost_{prod} + Cost_{env} + Cost_{maint} \tag{15}$$

where

- $Cost_{prod}$ is the unit production or lost opportunity cost, and can be determined using the following expression [29]:

$$Cost_{prod} = Unit_{prod} \cdot \left(\frac{Rate_{red}}{100}\right) \cdot D_{sd} \tag{16}$$

- $Cost_{env}$ is is the environmental costs due to a bundle leak
- $Cost_{maint}$ is the cost of maintenance to pull the bundle and make it ready for inspection or replacement.

For the presented heater and the given conditions, the values presented in Table 5 are obtained.

Table 5. Values of the *cost* for the heater (in EUR)

$Cost_{prod}$	1,000,000.00
$Cost_{env}$	100,000.00
$Cost_{bundle}$	500,000.00
$Cost_{maint}$	400,000.00
C_f	2,000,000.00

Based on obtained values, the calculated risk is R= 1495062. The results have been presented in the ISO-risk plot for the consequence of failure in Figure 17.

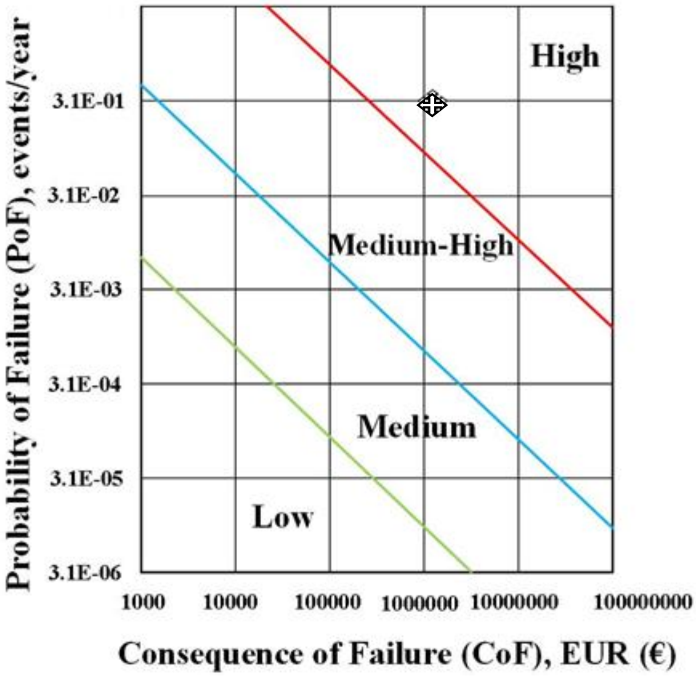

Figure 17. Iso-risk Plot for Financial Consequence

According to the previously mentioned calculation and according to the diagram will be concluded that examined vertical fired heater belongs to high level risk.

Conclusions

The paper presents one of the main parts of the gas purification process in the part, which is related to treatment gas in the Gas fired heater. The mentioned gas heater belongs to the construction of a fired heater with vertical tubes, which have been installed in the radiation zone and the heater has been switched off in the plant for the needs of determination of its status after long time service. During this opportunity, it was performed detailed visual examination of the exterior and interior of the apparatus, such as penetrant tests of the weld joints and ultrasonic thickness testing of the vertical tubes in the radiation zone. On that occasion, it was observed that weld joints around thermocouples and weld joints at fixed tube support had cracked. These defects were detail cleaned by grinding and successfully repaired by welding which has been proven by penetrant tests after repair welding activities. Penetrant tests were also performed in the area of connections of the vertical tubes and elbows and at the time of examination, cracks were not observed. Throughout the visual examination, also it was performed measuring minimum free dilatation lengths in the vertical tubes and their comparison with maximum dilatation for this material, and this analysis has shown that it will not start cracking in the operative period. Based on the results of ultrasonic thickness testing it was observed that corrosion and erosion of the tubes were present and that the estimated corrosion rate (LT) was 0.1156 mm/year while the calculated remaining life at this moment is 18.86 years. Together with all mentioned it was confirmed that the number of working hours in the previous period was 84300 hours and design parameters have also been analysed. Besides previously mentioned it was conducted measuring of temperatures by using thermocouples and on that occasion, it was concluded that values of temperatures in some moments have reached around 700°C that is it was proved that the apparatus works in a deep creeping regime. During analysis, it was observed that due to this discrepancy (interruption) in the working regime low distortion of the vertical tubes started. Based on this it can be concluded that of metallography examination should be performed after the next 15000 working hours such as ad and visual dimension control of the vertical tubes.

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