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Analysis of Nozzle Damage on Hydrocrack Unit During Media Mixing

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Nozzles of equipments and pipelines are exposed to loading of inner overpressure and force effect in pipes as well as loading from temperature fields' changes caused by mixing of streams of various temperatures and velocity. These processes have to be thoroughly analyzed and degree of hazardousness has to be determined with respect to service lifetime of nozzles and/or pipelines. Up-to-date approaches are applied here, such as numerical simulations of streaming with subsequent stress analyses.

Introduction

There are three basic types of streaming of cool medium after it has entered preheated branch. The type of streaming depends on diameters of connected pipes, on stream rate of the mixed media and on geometric design of pipe connections how present Muramatsu (2003). First, there is a medium of low velocity streaming in connected pipe and of high velocity in the main pipe; this has a consequence of main pipe stream usurping the stream from the connected pipe. Second, there is a medium of a higher velocity in the connected pipe and lower velocity in the main pipe, the stream consequently gets stabilized in the middle of the medium streaming in the main pipe. Third, there is a medium of a high velocity in the connected pipe and low velocity in the main pipe and the stream of the medium is driven at an opposite wall of the main pipe.
Characteristics of the final streaming of mixed streams are very important since they influence the distribution of temperature fields which consequently determine damaged areas where stabilizing of temperatures leads to stress state changes, i.e. fatigue.

Analysed issue

This paper presents an analysis of connection of pipelines before unit reactor NHCU (PS 1320) at Česká rafinérská, company in Litvinov (Czech Republic). Dimension of the connected pipe is DN 12″/8″, it serves for mixing of liquid spraying (vacuum distillate) with recycle gas (86 % H_2) and is located before R01 reactor supply. The analyzed nozzle was a nozzle with an inner inset made of austenitic steel SA-312. Its geometry and dimensions are presented in Figure 2

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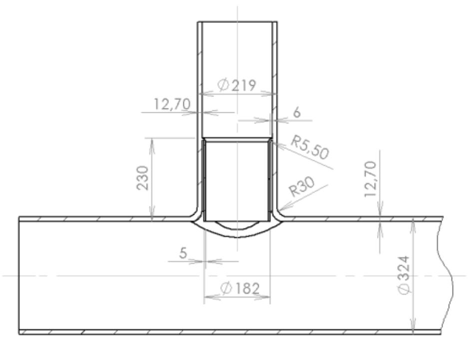

Figure 2 Geometry of analysed nozzle

Objective of the analysis was to determine damage accumulation for a particular process of unit start-up to operation stabilization. Stabilization of operation conditions may be represented by operation pressure of 16 MPa, weight flow of 130 t/h in the main pipe and temperature of 360.8 °C, flow rate of 24.8 t/h in the connected pipe and temperature of 417.2 °C. Changes in operation parameters always occur during start-up with significant impact on pipe service lifetime. Pressure changes presented in Figure 3 are very important. Difference in temperatures of mixed media greatly contributes to accumulation of damage. Velocity of mixed streams and diameters of connected pipes influence thermally affected areas, which is described in detail in introduction of this paper.

It was unnecessary to simulate the whole process of start-up since the changes in operation parameters during start-up of the unit are continuous. Fourteen conditions having highest impact in pipe damage were selected. These conditions were calculated as steady-state CFD analyses.

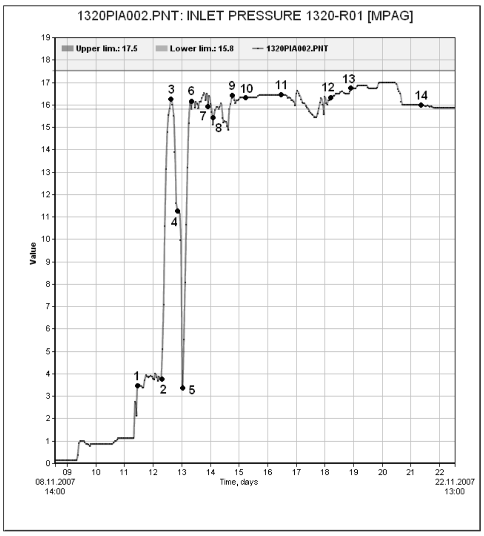

Fig. 3 Course of pressure during unit start-up

1.1 Thermo-hydraulic and stress analyses

Performed analyses of individual conditions of stream mixing provided us with stabilization of stream fields and distribution of temperature fields which are important for calculation of stress state in pipe material. Since the flow rate in the main pipe was much higher than in the connected pipe, it had a consequence of usurping the stream how present Moinereau et al. (2001). Inner inset is an important element in prevention of temperature influencing of the area of connection of the main pipe and feed pipe in the direction of the medium streaming in the main pipe. Inset also affected medium to circumflow and influence different nozzle areas. Figure 3 on the left displays distribution of velocity by using streamlines.

Streamlines help depict nature of mixed media streaming as well as visualization of streaming media trajectories. Inlet medium streamlines from the feed pipe are clearly visible, streamlines running through aperture between inset and connected pipe. This proves that high stream velocity results in stream being driven at the inset and medium being forced to circumflow it. This is advantageous since the heat that is transmitted to the inset is partially used for heating of the cooling medium that streams through the inset. Thus there are no high temperature differences concerning medium mixing. On the other hand though, there is a possibility of increase in temperature gradients in the area of inset connecting to the pipe with a consequence of high stress state which could result in undesirable deformations of nozzles if repeated.

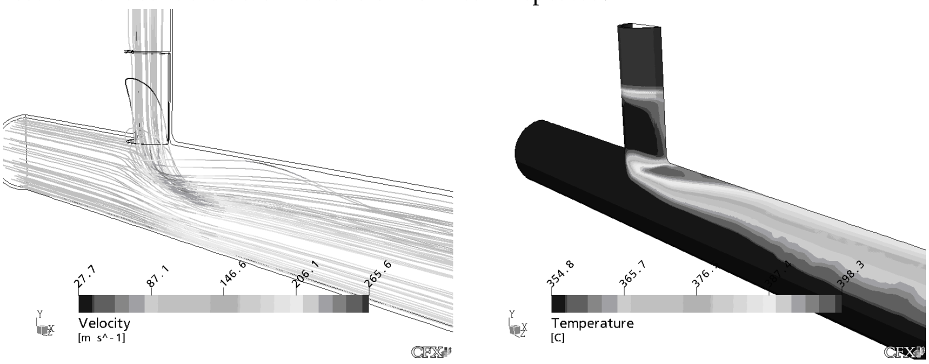

Figure 3 Distribution of velocity and temperature fields

Distribution of temperature fields (see Figure 3 on the right) is a decisive factor as to the stress state in nozzles and should not be dependent upon hot medium entering the cool pipe and vice versa how present Benhamadouche et al. (2003). Temperature difference of the two streams has the biggest impact. The analysed conditions revealed interesting distribution of temperature fields in the area of inset welding, at the inset and thermally influenced area of main pipe.

Data concerning temperatures and pressures were exported from CFD programme. These files were later used as boundary conditions for stress analyses. It was discovered that circumferential and longitudinal stresses can be considered to be the highest. Connection of the pipe is the most loaded area. There is also a significant stress in the main pipe that was influenced by heat. Among other influenced areas there is a connection of inset to the pipe Inner inset shows high amount of stress too but inset itself is not important concerning operation safety, thus it will not be considered for fatigue assessment.

1.2 Fatigue assessment of the nozzle

Stress state analyses showed that biggest changes in stress state occur in first half of the start-up process; second half of the process reveals little changes. Impact of temperature difference of individual streams proved to be significant for various cases how reported Chapuliont et al. (2005). As already mentioned in the previous chapter, study of stress state analysis during unit start-up identified four most loaded areas which are presented in Figure 4.

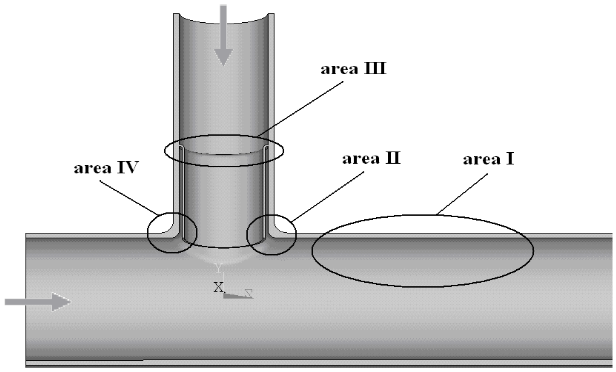

Figure 4 Most loaded areas

Calculations of mechanical fatigue damage as well as its accumulation were carried out in STATES programme. Damage accumulation was calculated for low-cycle fatigue using Langer lifetime curve. How present Vejvoda and Vincour (1997) numbers of allowable cycles is define as

$$\frac{\varepsilon_{at}}{\varphi_w \varphi_C \varphi_F \varphi_M} = \frac{e_C}{f_1(p_{fs})(4[N_o]_1)^m} + \frac{\sigma_{FR}}{f_1(p_{fs})E\left[(4[N_o]_1)^m + \frac{1+r_\sigma}{1-r_\sigma}\right]} \quad (1)$$

or

$$\frac{\varepsilon_{at}}{\varphi_w \varphi_C \varphi_F \varphi_M} = \frac{e_C}{(4f_2(p_{fs})[N_o]_2)^m} + \frac{\sigma_{FR}}{E\left[(4f_2(p_{fs})[N_o]_2)^m + \frac{1+r_\sigma}{1-r_\sigma}\right]} \quad (2)$$

and damage accumulation as

$$\Delta D = \sum_{i=1}^{q} \frac{n_i}{[N_o]_i}\,. \quad (3)$$

φ_w, φ_C, φ_F, φ_M are coefficients of strength reduction, ε_{at} is strain, e_C is characteristic of plasticity, $f_1(p_{fs})$, $f_2(p_{fs})$ are safety functions, $[N_o]_1$, $[N_o]_2$ are numbers of allowable cycles, σ_{FR} is fraction strength, E is Young's modulus, m is exponent and r_σ is asymmetry parameter of cycle.

Safety to stress coefficient of $n_\sigma = 2$ and safety to cycle amount of $n_N = 10$ was taken into account. Above mentioned areas were considered. Each area was represented by the most loaded points. Table 1 displays calculated damage accumulation and corresponds to one cycle loading (one start-up of the unit). As the results show, damage accumulation is not very significant. However, should these processes regularly repeat, lifetime service of the pipeline would decrease rapidly. Moreover, conservative Langer lifetime curve was applied. If there were fatigue tests for concrete types of material conducted, it would provide us with Manson-Coffin curve which gives lower values of damage accumulation.

Table 1 Damage accumulation of individual areas

	area I	*area II*	*area III*	*area IV*
D [-]	$1{\cdot}10^{-5}$	0.0084	0.0002	0.0061

Verification of numerical simulations

Measurements are performed for concrete pipelines so that accuracy of distribution of temperature fields obtained in CFD analyses may be verified. This concerns measuring of surface temperature using thermo-couples and continuous recording into memory of measuring equipment. These data are later assessed and analyses are conducted for some of the operation conditions so that calculation models and real measured data correspond. Figure 5 presents installed thermo-couples on the pipe surface and logger where the measured data are collected and stored.

Figure 5 Measurements performed at the hydrocrack nozzles

Measurements with thermovision camera are planned for further verification of hydraulic simulation of concrete nozzles; these measurements consist of measuring of temperature spectra during mixing of media streams of various temperatures and velocities. However, it is crucial to record what the operation conditions were like so that they can be later retrieved in numerical simulations.

Conclusions

Thermo-hydraulic analysis proved that stream is drifted from the connected branch. Stream of the medium is driven at the inset due to high velocity of streaming in the main pipe, medium is thus forced to circumflow the inset and flows through the aperture between inset and connected pipe.

Stress analyses proved that connection of the pipe, area of main pipe thermal influence and connection of inset to the pipe are among the most loaded areas. Inset itself shows a high degree of stress state but on its own the inset is not important for operation safety. Fatigue analysis proved that the most damaged areas (0.84 and 0.61 %) are pipe connections, i.e. areas no. II and IV. Damage accumulation is not very high; however, number of start-ups should be considered and monitored. Other assessed areas show low degree of damage accumulation. Analysis of start-up course revealed that start-up and sudden pressure drop to its quarter value and subsequent repeated rise significantly contribute to damaging. Damage accumulation will thus be distinctly lower if these cycles could be eliminated by proper technology.

Acknowledgements

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