

# Damage of Tubular Equipment in Process Industry

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**Abstract**—Tubular process equipment is often damaged in industrial processes. The damage occurs both on devices working at high temperatures and also on less exposed devices. In case of sudden damage of key equipment a shutdown of the whole production unit and resulting significant economic losses are imminent. This paper presents a solution of several types of tubular process equipment. The causes of damage and suggestions of correction actions are discussed in all cases. Very important part is the analysis of operational conditions, determination of unfavourable working states decreasing lifetime of devices and suggestions of correction actions. Lately very popular numerical methods are used for analysis of the equipment.

**Keywords**—creep, damage, fatigue, FEM, FSI, lifetime, tubular equipment

## I. INTRODUCTION

THERE are several causes that can lead to damage of equipment. One of the most important is an improper design of the equipment. This appears in very short time after the equipment is brought into operation. Another cause decreasing the lifetime of the equipment is a small mistake in design. Such mistake appears significantly later (sometimes after few years). Incorrect operation of the equipment also significantly decreases its lifetime, so it is necessary to avoid such situations. The ideal and also the planned process of equipment damage is a lifetime decrease resulting from operational conditions normal for this equipment. But this is very uncommon in many plants because of unpredictable situations.

Tubular equipment for steam production that works at given temperatures and pressures is commonly designed on the basis of the requirements of different standards, mostly according to the ASME and the EN regulations. These standards specify minimal requirements on particular parts of equipment, such as checking of thickness of tubes' and collector's wall, assessing of isolated openings and bottoms and assessing of creep load. In many cases an assessment of fatigue is required. Because of insufficient requirements of the standards the tubular equipment is damaged very often. One of the most frequent flaw is that the checking dilatation calculation is not carried out (it is not commonly required by the standards).

## II. USING MODERN METHODS TO SOLVE CASES OF DAMAGED INDUSTRIAL EQUIPMENT

Because industrial equipment is designed for specific operating conditions via design calculations, it is not possible to discover all possible critical spots of the equipment and

unfavourable working states that influence the decrease of the equipment's lifetime. They can be determined via detailed checking calculations that are always carried out only in case of equipment working in nuclear power engineering. In case of some insignificant equipment these calculations are irrelevant, but they are required in conclusive documentation, so it is necessary to carry them out.

In case of equipment in other industrial branches (petrochemistry, chemistry, pharmacy etc.) it may be appropriate to carry out detailed checking calculations, particularly in case of key equipment, dangerous equipment and in case of equipment, which damaging and shutdown would cause significant financial losses due to it being out of order. These undesirable situations can be avoided by detailed analysis of operating conditions, by determining the influence of particular situations on decrease of the equipment's lifetime and mainly by working out a plan of revision controls that are crucial for achieving the maximal lifetime of the equipment.

As it is not possible to assess equipment only from the operational temperature and pressure point of view, a very often used method for solving different kinds of tasks is the method of interactions of CFD and FEM analysis (FSI). These interactions of heat-hydraulic and tension analyses are called Fluid Structure Interaction (FSI). This method has been frequently used for solving different tasks in many industrial branches for several years [1], [2]. One of the possible procedures of solving tasks with the FSI method including assessment of fatigue is depicted in the Fig. 1 It is an analysis of a nozzle where flows of different temperatures and flow rates are being mixed.

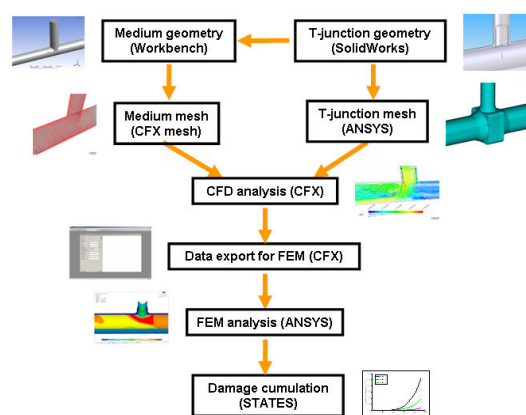


Fig. 1 Diagram of design procedure of the FSI method including the assessment of fatigue

Thanks to the FSI method influences of the current speed and the distribution of temperature fields that contribute significantly to fatigue damaging of critical parts of the

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equipment are taken into account. This is often omitted in case of common calculations.

### III. EXAMPLES OF SOME REAL-LIFE CASES

In case of some examples from industry it was not possible to determine the cause of the damage on the equipment on the basis of stress analysis and operational temperatures and pressures alone. In these cases it was appropriate to use the CFD analysis so that it was clear, which states take place and how temperature fields are distributed. In following chapters two particular cases are described.

#### 2.1 Waste-heat Boiler

In this case it was an economizer of a waste-heat boiler, where after certain operation time spots where pipes connected to collectors were being damaged. It was not possible to determine the cause of the damage on the basis of operational conditions, because the stress in critical regions was negligible. Based on analytic heat-hydraulic calculations and CFD simulations the distribution of temperature fields was determined thus making this problem clear. The crucial problem was the low speed of water in the economizer and its imperfect distribution into other pipes. Because of that the speed in pipes under the distribution piping was high and in surrounding pipes it was significantly lower. In some of them the emerging negative pressure even caused flow in opposite direction (in the Fig. 2 on the left there are depicted the flowlines of medium in the correct direction, those not depicted flow in opposite direction).

Because of the uneven flow of medium the pipes were unevenly heated and those that were cooled better were gradually damaged. In the Fig 2 on the right one can see the stress distribution in critical areas near the connection of the pipes to the collector. Here there are apparent increased stress values in welded joints that were gained via stress analysis of temperature fields obtained from previous analyses and that confirm the cases of damaging in these areas.

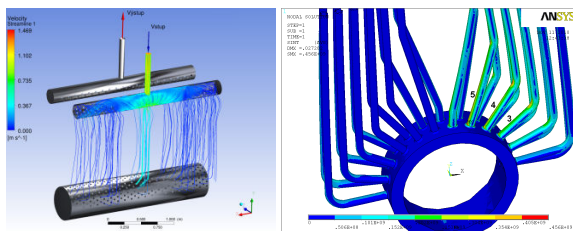


Fig. 2 The results of CFD and FEM analysis of the economizer

The corrective action in this case would be to come with more appropriate structural design that would distribute the working medium better (the input and output piping must not be placed perpendicularly to the collectors but from the side) and that would be able to compensate the dilatations of the tube nests (avoid the connection of many pipes of small dimensions on firm piping of a large dimension). Thanks to these modifications it is possible to ensure a trouble-free operation of the boiler. Revision controls that must be planned and carried out should not be underestimated though.

#### 2.2 Fluidized Bed Boiler for Steam Production

The second case solved in practice was a connecting piping of individual drafts of the evaporator of the fluidized bed boiler. It was a special construction that should have eliminated the dilatation of particular pipe manifold and distributed the working medium from one coil to another better (see Fig. 3). The working medium was saturated steam with the pressure of 3.3 MPa and working temperature about 290°C.

When carrying out the classical stress analysis using the FEM it was discovered that in the welded joint of the pipe and the main pipe the maximum tension was about 150 MPa. But this value was not significant considering the used material. That is why the examination of temperature fields was carried out, because water was distributed into the main vertical pipe through a little pipe coupling to regulate the temperature of the steam. In the Fig. 3 the flowlines are depicted, thanks to which it was found out that the flow rates of the working medium are not the same in all the pipes. Thanks to this analysis the distribution of the temperature fields that is crucial from the stress point of view was obtained.

The discovered distributions of temperature fields were the end conditions for the stress analysis of the transfer tubular construction. Because the temperature fields were specified, there occurred areas where the stress increased significantly to 213 MPa (see fig. 3 on the left)

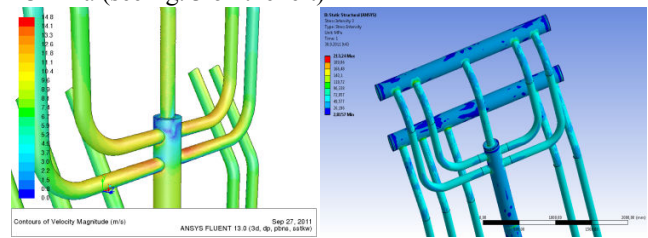


Fig. 3 The results of CFD and FEM analyses of the transfer pipe of the boiler

Among the factors not mentioned so far resulting in lifetime reduction are particularly aggressive corrosive environments, abrasive particles in the working medium and in the case of older equipment it can be a degradation of material.

### IV. CONCLUSION

When designing tubular equipment working under pressure and temperatures it is not possible by the means of requirements dictated by standards to cover all possible situations that can occur while operating the equipment. If the design organization does not carry out detailed calculations in case of key, dangerous or substantially expensive equipment this responsibility should be transferred to operators who can thus eliminate unexpected events that can influence the economy of a particular company. The practice has shown that a very applicable and strong tool is the combination of CFD and FEM analyses that is called the Fluid Structure Interaction. Thanks to the combination of these numeric methods it is possible to solve a number of ambiguous cases of damage that commonly occur in industrial plants. If companies were convinced about usefulness of prevention in this area, it could bring considerable advantages in lowering

the number of unexpected emergency situations that are financially very demanding.

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#### REFERENCES

- [1] O. VIRKKUNEN, I. Thermal Fatigue of Austenitic and Duplex Stainless Steels, Dissertation, Helsinki University of Technology, Department of Mechanical Engineering, Espoo, Finland, 2001.
- [2] MOINEREAU, D., BEZDIKIAN, G., FAIDY, C. Methodology for pressurized thermal shock evaluation: recent improvements in French RPV PTS assessment, International Journal of Pressure Vessels and Piping, 2001, vol. 78, pp. 69-83.