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PRELIMINARY ANALYSIS OF INELASTIC BUCKLING OF THE HEAT EXCHANGER

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Thermal and economic conditions that have to be satisfied by heat exchangers in heat and power generation cause that analysis of the influence of the working medium flowing in heating cartridge pipes is essential for designers. It follows from the state of the heating cartridge after its many-year operation. Because of strength issues that affect design and thermal solutions, it is important to evaluate the influence of heat exchanger working conditions on the possibility of its stability loss.
One of the most important elements of heat exchangers are perforated bottoms – perforated plates of significant thickness in which heating cartridge pipes are mounted. For designers of heat exchangers, the definition of loading and analysis of all possible types of failure is of special importance. The paper is a continuation of the conducted investigations on heat exchangers where the calculations of elastic stability of perforated bottoms with pipes inside were developed for inelastic regions.

Key words: heat exchanger, pipe, heating cartridge, stability, stress, displacement, emergency operation condition

1. Introduction

Heat exchangers operate in very high temperatures. The fact that differences in temperatures of various elements of the heat exchanger as well as different media that flow in it have to be taken into account very often results in serious problems in their designing process. The volume of materials used to build heat exchangers increases with an increase in temperature (dimensions of a jacket, perforated plates, etc., change). These are the so-called heat dilatations. The non-uniformity of temperatures that characterizes each heat exchanger causes that pipes elongate in a different way than a jacket does, and a perforated plate alters its diameter differently in comparison with the outer wall, etc. The differences in individual elongations that arise are sometimes followed by very serious stresses of the material, which can lead to permanent strains or even rupture. The jacket, pipes of the heating cartridge with a perforated plate are the place where most care is required in this respect. The jacket reaches a temperature close to the temperature of the working medium with which it comes into contact, whereas pipes have an intermediate temperature between the temperatures of both the media. It is followed by a considerable difference in heat elongations and, in turn, these elongations can be the reason of high stresses in the material the pipes, jacket and perforated plate are built of Hobler (1986).

For designers of heat exchangers, the analysis of vibrations of heating cartridge pipes due to the flowing working medium, which follows from their state after many-year operation and damages caused by the flowing medium, is very significant as well.

2. Problem under consideration

While analyzing the operation of the heat exchanger structure, it can be seen that the elements that are liable to stability loss are heating cartridge pipes with both ends mounted in perforated bottoms. Depending on the type of heat exchanger and its geometrical dimensions, they can be supported along their length by means of baffle plates. Inside the pipes, a fluid characterized by a certain pressure and temperature flows, and the pipes are flown around by steam or water (Concesion documentation, [3]). The displacements that arise in the heat exchanger can lead to damage of heating cartridge pipes through, for instance:

a) decrease in their wall thickness,
b) stability loss of pipes due to buckling,
c) cracks in pipe walls due to their collision with one another,
d) corrosion.

Strength calculations of heat exchangers are conducted for two conditions of their operation, namely: for the nominal operation and for the emergency operation.

The emergency operation occurs when the water intake and offtake are closed, whereas the heating steam is still supplied to the heat exchanger.

The problems of mutual effects of elastic systems and the flowing medium both inside and outside the structure are the object of analysis of phenomena of the fluid influence on the structure dynamics and evaluation of its stability. The determination of the influence of flow velocity and pressure of the working medium flowing in pipes (e.g. in the case of failure) on the vibration frequency of the structure is of significant meaning for designers of heat exchangers.

The analysis is carried out by means of, for instance:

- determination of the free vibration frequency of a bundle of heating cartridge pipes, taking into account the working medium flowing inside and outside of the pipes,
- determination of the vibration excitation forces,
- determination of the vibration amplitude, etc.

2.1. Theoretical basis (Hobler, 1986; Horak *et al.*, 2005)

Buckling, that is to say, stability loss of a rod, does not have to be followed by failure, however the effects it will exert on the whole structure depend on the kind and character of the buckling itself (elastic, plastic). It should be remembered that when the critical force is slightly exceeded, displacements in slender rods increase rapidly, which results in a considerable increase in stresses. In practice, it means that at the instant of buckling, the rod in a complex structure losses its load-carrying ability, which is followed by loss of the load-carrying ability of the whole structure.

The admissible value of the compressive force with respect to buckling can be defined by the following formula

$$\sigma_{dopw} = \frac{\sigma_{kr}}{n_w}$$

where n_w is the buckling factor of safety.

Figure 1 shows relationships for the critical stresses σ_{cr}, where: A, B, a, b denote constants, E – Young modulus, λ – rod slenderness.

In the literature devoted to issues of stability loss in thin-walled pipes, flow models in a single pipe have been considered so far (Einsfeld *et al.*, 2003; Jakubowicz and Orłoś, 1966). In Chudzik and Świniarski (2004), numerical calculations of stresses and strains for various thicknesses of the perforated bottom have been presented. The calculations have been conducted for the emergency operation condition and they have been aimed at the determination of strains occurring in the pipes, perforated bottoms and the jacket. It has been found that a decrease in the thickness of the perforated bottom increases its

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Fig. 1. Critical stresses σ_{cr} versus the rod slenderness λ

deflection, and thus the heating cartridge pipes are subjected to higher stains. The calculations have been carried out according to Huber's hypothesis, and some exemplary results of calculations are presented in the form of maps of reduced stresses in Figs. 2 and 3.

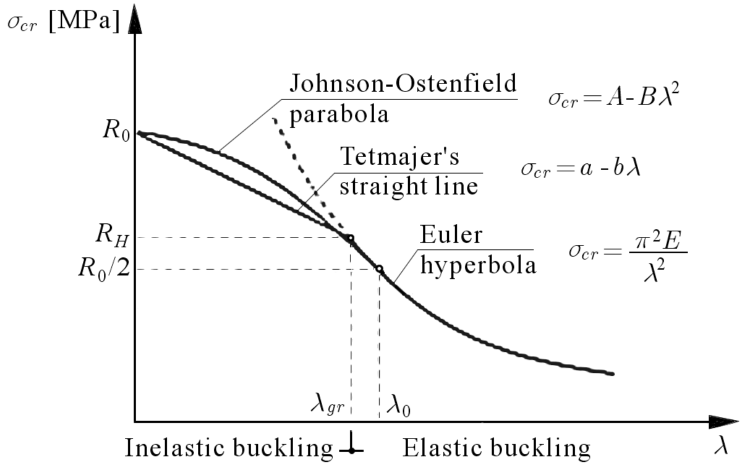

Fig. 2. Buckling mode corresponding to the lowest critical load

In actual heat exchangers, the number of pipes can reach even a few thousands, and analytical calculations for the whole device yield serious difficulties. Therefore, FEM calculations have been suggested for the evaluation of stability (Zienkiewicz and Taylor, 2005).

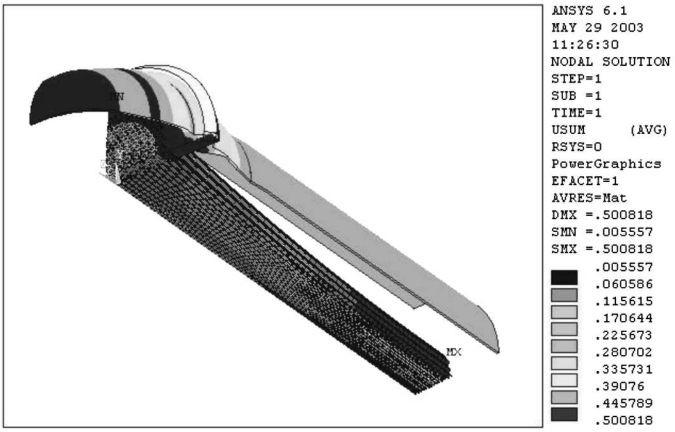

Fig. 3. Total strains of the heat exchanger [mm]

3. FEM calculations

3.1. Calculation model

A numerical model (Fig. 5) has been developed on the basis of the technical specification of the Py-100-020 decarbonized water heater (Concesion documentation, [3]), whose schematic view is presented in Fig. 4.

The basic elements of the heat exchanger are as follows: perforated walls 1, bottoms 2, jacket 3, heating cartridge pipes 8, and heating cartridge gaskets 10.

The perforated walls are mounted to the jacket and bottoms with screw fasteners 9. Connector pipes 6 and 7 supply water and take it off, whereas connector pipes 4 and 5 deliver steam. (B) shows dimensions of the hole in the perforated bottom before expansion of pipes and a view of the pipe-perforated bottom connection after expansion of the pipe.

3.2. Numerical model

The finite element method with conventional assumptions (User's Guide ANSYS 6.1, [14]) has been applied to numerical computations. Employing the symmetry conditions in the computations, a model depicted in Fig. 5 that represents 1/2 of the heat exchanger has been developed. The model has been divided into 8-node elements of the SOLID45 type (Chudzik, 2002). For the numerical strength calculations, professional ANSYS software packages have been proposed (User's Guide ANSYS 6.1, [14]).

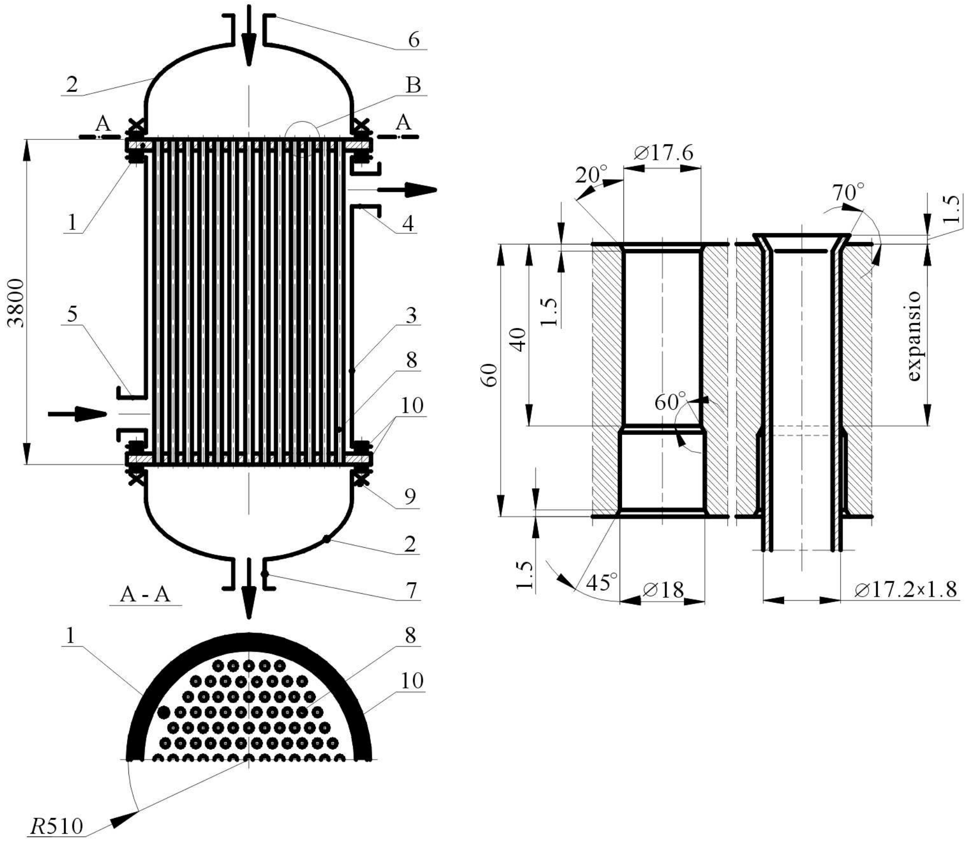

Fig. 4. Schematic view of the heat exchanger

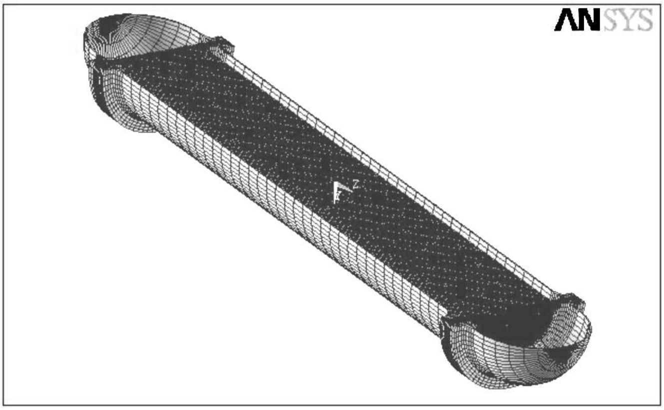

Fig. 5. Numerical model

Table 1. Properties of the materials assumed in the FEM calculations

	R_e [MPa]	E MPa]	ν [–]	Coefficient of reinforcement
St36K PN-75/H-92123 bottom	196	$2 \cdot 10^5$	0.3	0.99
St36K PN-75/H-92123 jacket	196	$2 \cdot 10^5$	0.3	0.99
St41K PN-75/H-92123 perforated bottom	255	$2 \cdot 10^5$	0.3	0.99
I-K10 PN-74/H-74252 heat exchanger pipes	235	$2 \cdot 10^5$	0.3	0.99
Polonit 300 PN-79/M-11022.02 gasket	–	$0.03 \cdot 10^5$	0.4	–

A non-linear model of the material with linear reinforcement has been assumed. It is postulated to carry out calculations for the case of failure, which would be aimed at the determination of strains occurring in the pipes, perforated bottoms and the jacket. The load acting on the gasket has been calculated on the basis of the initial tension of screws in the bottom-gasket-perforated bottom-gasket-jacket connection, given in the technical specification of the heat exchanger.

The values of loads and the emergency operation conditions are listed in Tables 2 and 3, respectively.

Table 2. Values of loads that result from the assembly

Load acting on the gasket	7.1 MPa
Pipe-perforated bottom expansion pressure	176 MPa

Table 3. Emergency operation conditions of the heat exchanger

Parameters	Water chamber	Steam chamber
Pressure	–	$p_0 = 1.17\,\text{MPa}$
Temperature	–	$T_0 = 523\,\text{K}$

4. Conclusions

Activities aimed at the optimization of the heat exchanger design are justified economically, because these devices are very complex and costly as far as their manufacturing is concerned. The proposed calculation model will make the

Table 4. Values of heat transfer coefficients

Steam-liquid convective heat transfer coefficient	$\alpha_w = 17\,\mathrm{W/(m^2K)}$
Liquid convective heat transfer coefficient	$\alpha_w = 29\,\mathrm{W/(m^2K)}$
Thermal conductivity coefficient through pipes	$\lambda = 49\,\mathrm{W/(mK)}$
Thermal conductivity coefficient through the perforated bottom	$\lambda = 47\,\mathrm{W/(mK)}$
Air convective heat transfer coefficient	$\alpha_w = 30\,\mathrm{W/(m^2K)}$

determination of stresses and displacements in the heat exchanger jacket and the heating cartridge feasible, which can be the basis for the optimization of dimensions of the exchanger.

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Analiza wstępna wyboczenia niesprężystego wymiennika ciepła

Streszczenie

Warunki cieplne i ekonomiczne stawiane wymiennikom ciepła stosowanym w energetyce powodują, że dla konstruktorów istotna jest analiza wpływu przepływającego czynnika w rurkach wkładu grzewczego. Świadczy o tym stan wkładu grzewczego po wieloletniej pracy urządzenia. Ze względów wytrzymałościowych rzutujących na rozwiązania konstrukcyjne i energetyczne, istotna jest ocena wpływu warunków pracy urządzenia na możliwość utraty jego stateczności.

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