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THE COMPLEMENT TO TUBE-SYSTEM DESIGN

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Abstract: *It is shown that a system with counter-current in- and outflow (U-type flow) in heat exchangers can lead to an even distribution in branched systems with given high temperature. The irregularity of flow distribution in branched systems can be reduced by optimization of the feeder and header diameters. The computation formulas for the feeder and header diameters are given.*

Keywords: ***Heat exchanger, U-type flow system, even flow distribution, optimization of diameters.***

1. Optimal design of feeder and leader diameters

For the high-temperature heat exchanger is proposed a U-type flow system and optimal diameter of feeder and header looked out. The simplest form of a mechanical energy balance Bernoulli´s equation for vertical feeder – Jirouš (2002), Jirouš (2010). Fig. 1, is defined

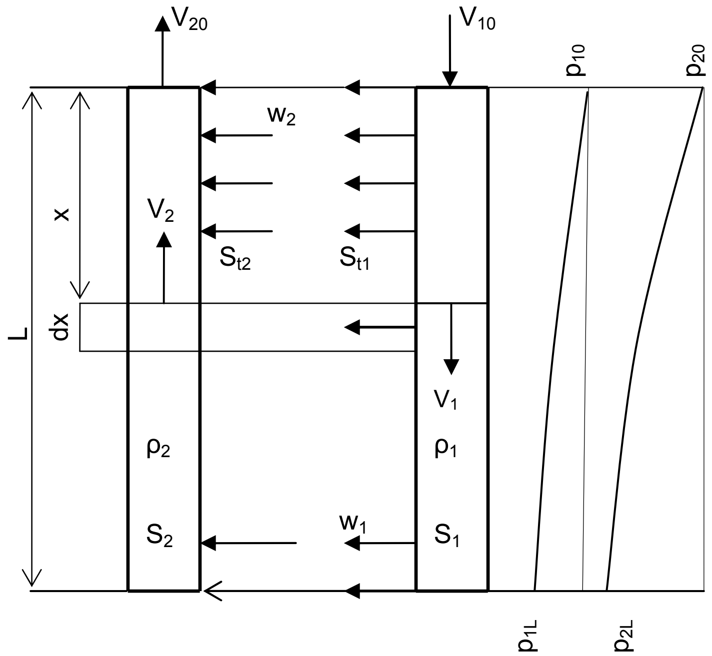

Fig. 1: U-type flow system.

$$\frac{dp_1}{dx} = -E.\rho_1.V_1.\frac{dV_1}{dx} + g.\rho_1 \tag{1}$$

with E factor of pressure gradient in the feeder, for vertical header:

$$\frac{dp_2}{dx} = -A.\rho_2.V_2.\frac{dV_2}{dx} + g.\rho_2 \tag{2}$$

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with A factor of pressure gradient in header. Pressure difference of fluid flowing in the tube becomes:

$$p_1 - p_2 = \zeta_V . \frac{\rho_1}{2} . w_1^2 \tag{3}$$

The pressure difference between pressure p_{10} and pressure $p_1(x)$ in feeder is:

$$\Delta p_1 = p_1(x) - p_{10} \tag{4}$$

Integrating (1) between points x = 0 and x:

$$\Delta p_1 = E . \frac{\rho_1}{2}\left(V_{10}^2 - V_1^2\right) + g.\rho_1.x \tag{5}$$

The pressure difference between pressure p_{20} and pressure $p_2(x)$ in header is:

$$\Delta p_2 = p_2(x) - p_{20} \tag{6}$$

and integrating (2) between points x = 0 and x:

$$\Delta p_2 = A . \frac{\rho_2}{2}\left(V_{20}^2 - V_2^2\right) + g.\rho_2.x \tag{7}$$

Under conditions of

1. The pressure in feeder $p_1 = \text{constant}$ and in header $p_2 = \text{constant}$
2. Fluid velocities from feeder in a tube and from tube in header are constant velocity of fluid:

$$\overline{w} = \frac{m}{S_t . \rho} \tag{8}$$

3. Flow cross-section of tubes S_t is replaced by a crevice with the length L and latitude:

$$b = \frac{S_t}{L} \tag{9}$$

Mass balance in feeder element yields:

$$S_1.V_1.\rho_1 - b_1.dx.\overline{w}_1\rho_1 = \left[S_1.V_1 + d\left(S_1.V_1\right)\right].\rho_1 \tag{10}$$

therefore the fluid velocity in tubes is:

$$\overline{w}_1 = -\frac{L_1}{S_{t1}} . \frac{d\left(S_1.V_1\right)}{dx} \tag{11}$$

This equation shows that:

$$d(S_1.V_1) = -\frac{m}{L_1.\rho_1} dx \tag{12}$$

The integration gives:

$$S_1.V_1 = \frac{m}{\rho_1} . \left(1 - \frac{x}{L_1}\right) \tag{13}$$

if for x = 0:

$$S_1.V_1 = S_{10}.V_{10} \tag{14}$$

Hence both:

$$\frac{dp_1}{dx} = \frac{dp_2}{dx} = 0 \tag{15}$$

From (1) is given:

$$V_1.dV_1 = \frac{g}{E} dx \tag{16}$$

The integration yields, if for x = 0 $V_1 = V_{10}$:

$$V_1 = \sqrt{\frac{2g}{E}.x + V_{10}^2} \tag{17}$$

By substitution in equation (13) the optimal cross-section of feeder is:

$$S_{1OPT} = \frac{m}{\rho_1}\left(1 - \frac{x}{L_1}\right).\frac{1}{\sqrt{\frac{2g}{E}.x + V_{10}^2}} \tag{18}$$

for horizontal feeder:

$$S_{1OPT} = \frac{m}{\rho_1.V_{10}}\left(1 - \frac{x}{L_1}\right) \tag{19}$$

Mass balance in header element yields:

$$S_2.V_2.\rho_2 = S_2.V_2.\rho_2 + d(S_2.V_2).\rho_2 + \frac{S_{t2}}{L_2}.\rho_2.\overline{w}_2 dx \tag{20}$$

Analogous advancement as by feeder for the optimal cross-section of header yields:

$$S_{2OPT} = \frac{m}{\rho_2}\frac{1 - \frac{x}{L_2}}{\sqrt{\frac{2g}{A}.x + V_{20}^2}} \tag{21}$$

and for horizontal header:

$$S_{2OPT} = \frac{m}{\rho_2.V_{20}}\left(1 - \frac{x}{L_2}\right) \tag{22}$$

2. Verification of analytical model and design calculation of distributing and collecting chamber of steam-air mixture heater

Steam-air mixture heater is a special high temperature radiation - convection heat exchanger used for heating of steam-air mixture to a temperature of about 835 °C, by flue gas of inlet temperature of about 1100 °C.

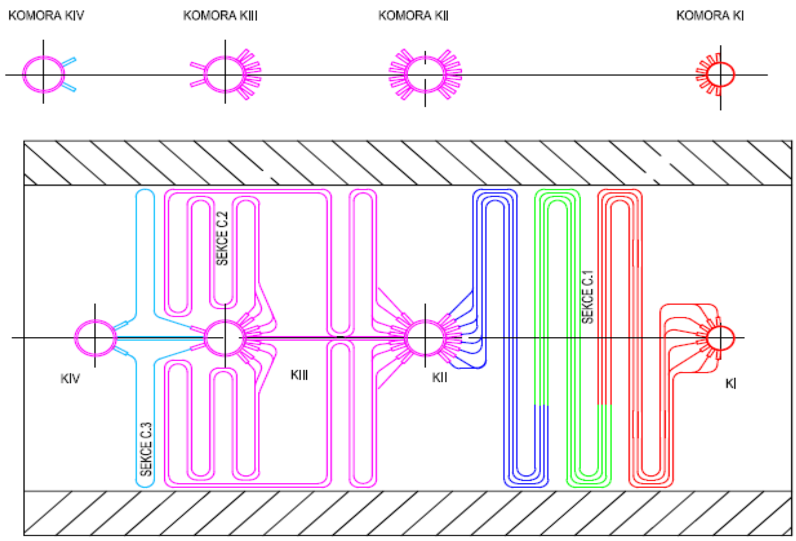

Fig. 2: Heat exchanger for heating steam – air mixture.

Due to the high temperature flue gas is necessary to ensure a high degree of hydraulic uniformity of steam-air mixture flowing in the tube system and at the same time ensuring of maximum allowable temperature of chamber walls KIV insulated with Sibral. For this purpose, the mathematical model was created in ANSYS CFX software. First, it was done a calculation of general type of chamber KIV (Fig. 3), which served to verify of the analytical mathematical model (Fig. 4) and to determine the maximum surface temperature of the chamber wall. The results of the change process in static pressure along the chamber confirmed a high degree of congruence between the two models.

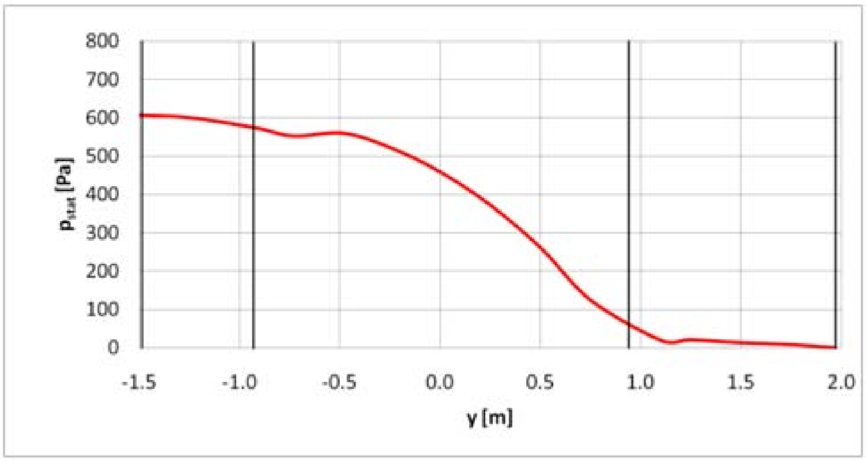

Fig. 3: Process of difference of static pressure with CFD method.

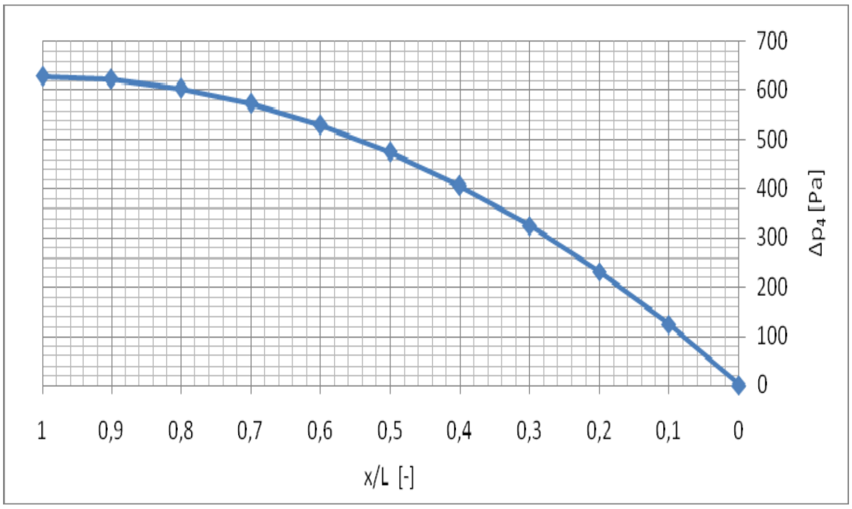

Fig. 4: Difference of static pressure of analytical calculation with A factor 2.2.

3. Conclusion

With regard to the observed surface temperature of the chamber it was abandoned for the general type variation and through a series of calculations using CFD methods (Computational Fluid Dynamics) it has been proposed optimal geometry of KIV chamber, which serve to modify of flowing and thus increase the heat removal from the chamber. Due to the increase in value of difference of static pressure in the length of the collecting chamber KIV compared to general type variation of chamber it was made a calculation of new section of distributing chamber KI by analytical model in order to maintain the same degree of hydraulic uniformity of flowing in the tube system as in the option of general type variation of chambers. This calculation was necessary with regard to maintaining of the same internal diameter of the chamber KIV.

References

Jirouš, F. (2010) Applied heat and mass transfer. CTU Press, Prague, (in Czech).

Jirouš, F. (2002) The equations of flow distribution in header systems of steam boilers: Proc. 8th Int. Conf. on Engineering mechanics 2002. Svratka, Czech Republic 13-16 May, 2002, (in Czech).