Summary

One of the most important challenges of designers today is the desire to reduce the dimensions of the devices, and at the same time maintain their high efficiency. For this purpose, maintaining proper heat transfer as well as intensification of mass, energy and momentum transportation is a necessity. Cross-flow heat exchangers are no exceptions and are impossible to achieve obtaining correct working fluids flow inside the tubular space with using today's technology solutions of inlet and outlet manifolds (in some cases also reversing manifolds). Lack of an even liquid flow in each individual heat exchanger tubes are cause of improper heat transfer in some of them. This is particularly valid for elliptical tubes - often used because of their advantages compared to round tubes, including lower pressure drop and more favorable heat transfer conditions. In comparison with round tubes, the elliptical tubes have a better aero-dynamic shape, which results in a lower pressure drop of working fluid flowing through the inter-tubular space of heat exchanger. They not only perform better in fewer pressure loss but also distribution of velocity is more favorable in flow zones which are reduced. Effectively we observe significantly higher heat transfer coefficient from gas to inside the tube walls due to intensive heat exchange process. In consequence the overall dimensions of the device are reduced in relation to that in which round tubes are used.

Disadvantage for this type of heat exchangers is an uneven distribution of liquids in each tube. The reason behind this phenomenon is manifolds present shape as well as relatively small dimension of inlet and outlet manifold. Above fact causes variable speed rate of fluids inside the heat exchanger and in some cases, they can be even opposite to desired outcome. In results we are facing unfavorable operating conditions including high thermal compressive stresses due to overheated tube walls.

Analysis of discussed heat exchangers working conditions indicates that flowing liquids in elliptical tubes can occur in all regimes i.e., laminar, transitional and turbulent. Location of damages proves that in these devices as well as numerical simulation of thermal-flow studies. Transient flow is particularly difficult for mathematic modeling for such complex occurrence. This is still not fully studied and understood and there are several possible correlations allowing the determination of heat transfer coefficient from wall to flowing liquid inside the tubular space. Not always a specific model of turbulence: k-ε, k-ω, SST or SST-TR allows to determine the correct values of the heat transfer coefficient, especially for tubes horizontally arranged.

Their use in numerical calculations during various analyzes requires evaluation and confirmation of their suitability (in the case of the discussed devices, i.e., for determining liquid parameters such as flow velocity or temperature distributions). Therefore, developed mathematical models require experimental verification, especially for the transient flow.

This Dissertation presents two research stand outs in the Department of Energy, at Cracow's University of Technology and the measurement data were used to evaluate the results obtained from numerical calculations, especially in the transitional flow regime.

The first stand determines the heat transfer coefficient from the wall to the flowing medium (water) inside the elliptical tube. The base is an elliptical tube and the remaining elements are; water tanks, feed pump, cooler, fittings and connection fittings, heating system supply, regulation system, control and measurement equipment. To obtain a constant density of the heat flux weighting out the elliptical tube, a resistance wire was used, alternately winded up with an insulating cord on the outer surface of its measuring section.

The analysis of measurements data was obtained on the stand to determine the heat transfer coefficient and compared with CFD simulations, using the SST-TR model, indicating relative error of the average water temperature at the outlet from the measuring section which does not exceed 4.4%. The average temperature of the elliptical tube wall near its inner surface (in the exit zone) is very close, and the relative error is about 1%. However, the relative error of the numerically determined value of the heat transfer coefficient is higher and reaches about 11%.

The results of experimental measurements confirm the compatibility with CFD simulations; therefore, it can be concluded that the proposed methodology for determining the heat transfer coefficients is correct in the full range of flows: laminar, transient or turbulent. On the other hand, the well-known correlations of the heat transfer coefficient determined by Gnieliński or Dittus-Boelter correctly predict flows in the laminar regime. In the case of transient and turbulent flows, the difference between the experimental results and CFD simulations is very high and it is not recommended to use these correlations when modeling these flows.

The second measurement stand of which is a heat exchanger, is situated vertically and consists of 20 elliptical tubes arranged staggered in two rows. The stand consists of the following elements: feed water tank, circulation pump, steel and flexible tubes, total flow meter, inlet and outlet manifolds, ultrasonic flow meters on each of the tubes.

The obtained measurement results confirming fact that the flow of the working medium inside tubular space of cross-flow heat exchanger is characterized by non-uniformity. Results of measurements presented in the dissertation shows that, greatest differences in flow relate to the tube located under inlet nozzle.

The CFD simulation results confirm compliance with obtained results of experimental measurements. Slight discrepancies are observed in downstream of the inlet nozzle, where the CFD simulation predicts a slightly higher flow rate, while lower flow rates are calculated near the inlet nozzle. Therefore, for an elliptical tube with internal flow Re from 1800-3100, the SSG Reynolds Stress Transport turbulence model provides a satisfactory compliance with the measurement data.

The designed structures of the heat exchanger manifold allow to reduce uneven flow in the tubular space heat exchanger with elliptical tubes to the level of: 56% - laminar flow, 8% - transitional flow, 14% - turbulent flow.

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