Abstract

This PhD Thesis was carried out as part of the project POIR.03.02.01-18-0019/15-00 financed by the Polish Agency for Enterprise Development, in cooperation with an industrial partner - Retech Ltd. The project, titled *Implementation of anew generation of condensation hoods for combi-steamer* covers development of a new generation of condensation hood by means of computational fluid dynamics (CFD).

The condensation hood (CH) is a device widely used in gastronomy. It is designed to work with a combi steamer (CS) that produces a significant amount of steam. The steam is condensed by the CH in a dedicated heat exchanger (HE) and is returned to the oven that enables free relocation of the CS and allows for its normal operation without appropriate infrastructure. The steam has direct contact with food in the CS working chamber, and hence it can carry solid particles, grease droplets, and scents. The condensation hood captures them to avoid the nearest surroundings additional pollution. This, however, is not the subject of this dissertation.

Already mentioned heat exchanger, in which the CH is equipped with, has a non-standard construction: it consists of two bundles of internally finned tubes - 24 per bundle (48 in total). This results from the flow organisation, where coolant air flows through the pipes, while the steam around them contacts with their smooth outer surface. From the heat transfer point of view, such a solution has several drawbacks: firstly, the diameter of the tube (as well as the technological limitations) limits the number and geometry of the fins (which limits the overall heat transfer surface); secondly, the inner fins increase the tube's flow resistance; and thirdly, the steam flowing across the bundle in the inter-pipe space has low velocity ($\leqslant$1 m/s), which makes contact with the pipe's wall more difficult.

For the purposes of the project, and as part of this work, three condensation hood models were developed. All three models utilise user-defined functions (UDF) to perform the process of steam condensation and its heat exchange with the coolant air.

The simulations were steady-state with the use of the species transport model, which was enabled because of the implemented UDF. The main idea of the UDF was to remove the condensed steam from the computational domain, so the flow could remain gaseous. This allowed to reduce the mesh size by approximately an order of magnitude. The turbulent flow was calculated in the standard k-ε model using the standard wall function. Implementation of the UDF enabled not only a single phase flow simulation, but also allowed for the project's completion within limited resources and time.

The first numerical model concerns the original CH already produced by Retech company. In this work, it is denoted as OC - original construction. It was developed to validate the UDF model and to diagnose the actual device. As the condensation hood turned out to be overestimated, but with a very high condensation efficiency, amounting to approx. 90%, it was decided not to improve such high efficiency, and instead the focus was laid on simplifying the construction. The improvements developed in such direction were implemented in the second model.

The second numerical model (denoted as MC - modified construction) is an implementation of the most promising improvements to the HE design. Those improvements include: removal of 12 from 48 pipes, which equals to 25% of overall heat transfer surface - as a result total pipe length was reduced from 13.5 m (OC) to 10.1 m (MC) - which allowed to improve the steam distribution in the HE and to reduce manufacturing cost; modification of the size and location of the steam side baffles to extend the steam residence time in the inter-pipe space. Once the results were satisfactory, i.e., the condensation efficiency was maintained at 90%, it was decided to build a prototype, which was then successfully validated.

The last (third) numerical model is marked as RC - redesigned (new) construction. In this concept, the cooling air is rearranged so that it flows around the tubes and the steam flows inside them. This allowed to utilise tubes with external fins and reduce their number from the original 48 to only 5. Compared to the previous design, both bundles were merged into one large additionally equipped with an air side flow guide to enhance air distribution in the inter-pipe space. Total pipe length was reduced from 13.5 m (OC) to just 4.7 m (RC). As the obtained results were very optimistic, a new prototype was built, tested, and the model was validated. The RC is able to condense over 15% more steam, when compared to the original CH.

The redesigned construction was used as a basis for Retech in designing two new concepts of condensation hoods that are now in the company's offer.