Heat exchanger design hots up

Report by GARY TUCKER

This project was a 12-month Development LINK project that built on the findings from a previous project (AFM126) on innovations in heat recovery systems for tubular heat exchangers. In the previous project, laminar flow and heat transfer in the shell were of interest, whereas in this project, shell and tube flow with heat transfer under both laminar and turbulent conditions were considered. Commercial considerations dictated that any modifications to heat exchanger equipment required to promote heat transfer in heat recovery mode should also, ideally, result in enhanced performance in the conventional mode of operation.

This project, and its predecessor, concentrated on one particular type of shell and tube heat exchanger, namely a multi-tube heat exchanger with 7 tubes of external diameter 16mm and a shell of internal diameter 70mm (a Tetra Spiraflo MT 70/7x16C-6, as shown in Fig. 1). A number of design changes, aimed at improving the performance of the heat exchanger, were considered. Attention was first focussed on changes that improved the uniformity of flow distribution within the tubes of a tube bundle and in the shell around the tube bundle. Of primary interest were wall corrugation pattern, tube wall thickness, centre tube diameter and shell-side baffles.

By using CFD to experiment numerically with novel exchanger designs, it was possible to highlight the most promising features and thus reduce the quantity of real experimental testing. Computational work, carried out at the University of Plymouth, used the CFX code. The well-known k-ε turbulence model was used, as well as a 'shear-stress-transport' (SST) model incorporating more realistic flow physics near the tube and shell walls. Fig. 2 illustrates the improvement in velocity distribution by changing the tube bundle from 7x16 to one with a 12mm diameter centre tube.

Tetra Pak, as the equipment manufacturer, constructed and delivered to CCFRA a number of new tube inserts for performance testing, as described below. Each insert comprised two six-metre lengths of stainless steel exchanger for coupling to the existing Tetra Spiraflo mainframe[1]:
1) MT 70/7x16C-6, corrugation depth 0.75mm, wall thickness 1.0mm.
2) MT 70/7x16C-6, corrugation depth 0.75mm, wall thickness 0.8mm.
3) MT 70/6x16C-6+1x12S-6, corrugation depth 1.0mm, wall thickness 1.0mm (standard insert C-6 but with smooth 12mm centre tube).
4) MT 70/7x16C-6, corrugation depth 1.0mm, wall thickness 1.0mm (standard insert C-6 but with welded-on half-moon sector baffles).

Standard corrugated and smooth tubes were included as baseline tube inserts for data comparison. Data analysis used pressure drop and heat transfer coefficient improvements as the measures of success, with a 'goodness factor' that took into account both variables. Cost reduction, through reduced steel thickness and performance improvement, was equally important for longer term commercial prospects. Thus, the tube insert option 2) with reduced wall thickness was commercially important. Improvements of around 5-10% were estimated in 'goodness factor' for options 2) and 3), with all other tube inserts performing at similar levels. Goodness factor results

[1] In the code MT 70/7x16C-6, MT refers to multi-tube, 70 is shell diameter (mm), there are 7 tubes in the bundle, each 16mm diameter, with corrugated wall pattern and 6-metres long.

showed that the cost reduction changes did not adversely affect performance - a result with significant commercial importance.

Future plans

Commercial exploitation will initially be achieved with the ongoing improvement programme for Tetra Spiraflo tubes. Availability of CFD models for flow behaviour prediction will enable new exchanger designs to be evaluated prior to building prototypes. For example, changes in heat transfer performance were demonstrated computationally as a result of altering the depth of tube corrugations. However, it was questionable whether current manufacturing tolerances could allow these to be consistently reproduced in practice, which is an area that will be addressed in the future.

Several tube insert options have potential for exploitation. Sector baffles - a heat recovery option - were shown to result in higher pressure drops on the shell side and minimal advantage in terms of heat transfer coefficient. Issues with circulation zones and cleanability would preclude sector baffles from use in heat recovery with all foods except those of low viscosity. Computational work showed that longitudinal grooves in the shell were effective for heat recovery. Fig. 3 illustrates this in cross-section. These brought the shell wall in closer to the tubes and provided a more uniform gap between the tubes and the shell. Of all the designs considered, this gave the most promising exploitable technology for heat recovery. For heat recovery, the reduced diameter centre tube appeared to be the most realistic option for improvements, in that it offered improved flow in the shell with minimal impact on the tube-side heat transfer coefficient.

Project partners

This Defra AFM LINK project involved CCFRA, University of Plymouth, Tetra Pak Processing UK Ltd, ANSYS Europe Ltd, GlaxoSmithKline, Centura Foods Ltd, and HJ Heinz Co. Ltd.

FURTHER INFORMATION - AFM237

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Fig. 1: Illustration of a Tetra Spiraflo MT 70/7x16C-6

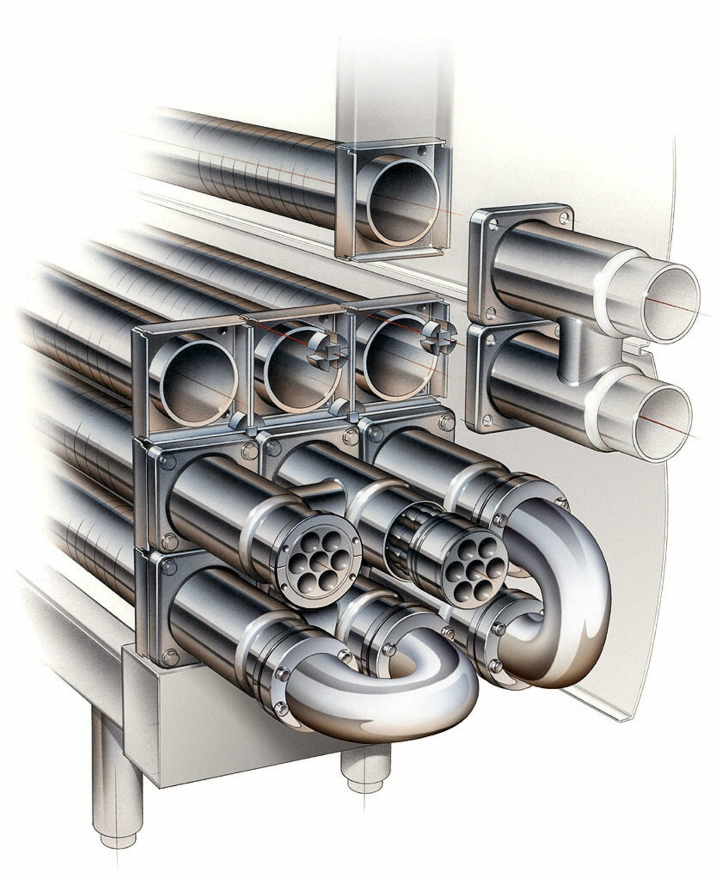
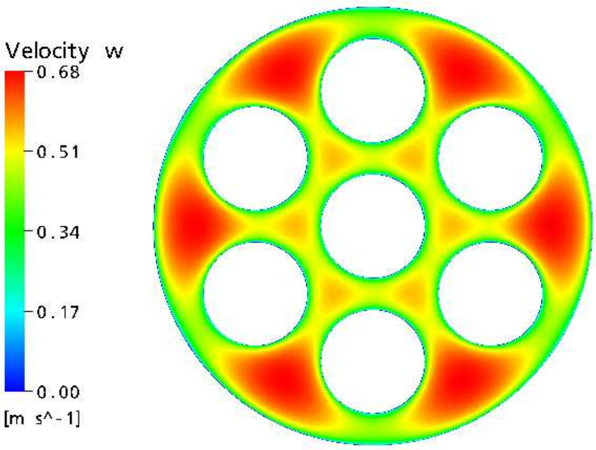


Fig. 2: Cross-section through the MT exchanger shell showing velocity distribution for a 7x16 and 6x16+1x12 tube bundle, at 30 L.min^{-1} flowrate.



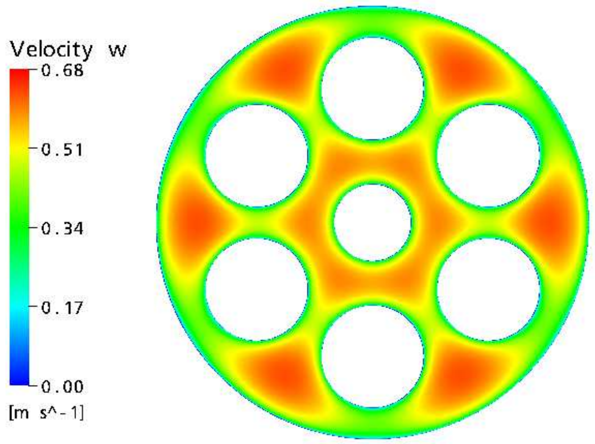


Fig. 3: Cross-section of the temperature distribution through an MT 70/7x16 shell with longitudinal grooves.