HEAT TRANSFER ANALYSIS OF A HEAT EXCHANGER PLATE*

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The objective of this study was to measure and evaluate the variation of the temperature and the overall heat transfer coefficient over a single plate.

Tests were conducted in the actual operating conditions, with the test plate in the regenerator section of a high-temperature short-time milk pasteurizer.

Copper-constantan thermocouples were used to obtain the data. The plotted contours of the temperature and the overall heat transfer coefficient showed pronounced variation near the inlet and the outlet ports. The overell heat transfer coefficient was observed to vary between 300 and 800 B.t.u./hr. ft.^{2}°F., with a weighted average value of 550 B.t.u./hr. ft.^{2}°F. over the surface of the plate. The temperature varied linearly along the length of the plate.

Plate type heat exchangers were introduced into the processing operation in the 1940's. Despite their limitations in withstanding temperatures and pressures higher than 300°F. and 150 p.s.i.g., they are very widely used in many food industries. Plate heat exchangers offer higher rates of heat transfer, greater flexibility, compactness and ease in cleaning, sterilization and inspection than many other types of heat exchangers.

A plate heat exchanger consists of rectangular metallic plates having corrugations on the surface. The corrugations, in addition to increasing the plate strength, help create turbulence. Turbulence is produced at Reynolds numbers as low as 180-200 (as compared to 2000-4000 in cylindrical passages). Alternate plates are provided with rubber gaskets along the periphery. When these are pressed together, the plates form rectangular flow passages of a thickness of 3-5 mm. The design of the flow pattern through the unit is dependent upon the design of the rubber gasket on the gasketed plates.

E.L. Watson et al.[1] have reported very valuable information concerning velocity flow pattern, pressure drop and the heat transfer characteristics of plate heat exchangers. Using motion pictures and conductivity tests, velocity profiles were determined. The investigation showed presence of air pockets in inverse ratio to the flow rates at values less than 1700 lb. per hour per plate. Air pockets were more pronounced for down flows than upflows. The overall heat transfer coefficients calculated from the energy balance of the system showed a linear increase with the flow rates.

This study was undertaken to measure and evaluate the variations of the overall heat transfer coefficient, U, B.t.u. per hr.-sq. ft.-°F. over a single plate. One of the gasketed plates from the regeneration section of a high-temperature short-time milk pasteurizer was used: the investigation was made in a plant milk pasteurization operation at a constant flow rate of 6920 lb. per hour.

Theoretical Considerations

The test plate with the flowing fluids is shown in simplified form in Fig. 1(b). Heat transfer through the plate at any location (I) equals:

$$Q_I = k_I A_I \frac{\Delta t_I}{x_I} = \frac{kA}{x} (\Delta t)_I$$

since k, A and x are independent of location, where Δt = temperature difference across the thickness of the plate, °F.; k = thermal conductivity of the plate material (18-8 stainless steel, 302 series), = 9.4 B.t.u. per hr.-ft.-°F.; A = projected area, sq. ft.; x = plate thickness = 0.00365 ft. (measured).

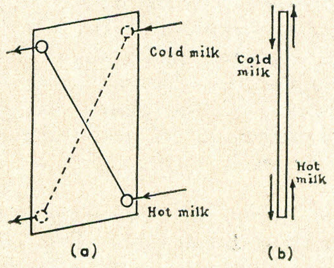

Fig. 1

*Based on M. S. thesis, Michigan State University, 1962, by the same title.

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Also heat transfer between hot and cold fluids flowing on either side of the plate at the same location (I) is:

$$Q'_I = A_I U_I (\Delta t_m)_I = AU_I (\Delta t_m)_I$$

where U = overall heat transfer coefficient B.t.u. per hr. ft.^{2}°F., Δt_m =mean temperature difference of the flowing fluids. At any location (I), it is the difference of the bulk temperatures of these fluids.

With steady state, heat transfer through the plate at any location is the same as between the two fluids

$$Q'_I = Q_I \text{ or } A\, U_I (\Delta t_m)_I = \frac{kA}{x} (\Delta t)_I$$

$$U_I = \frac{k}{x} \left(\frac{\Delta t}{\Delta t_m} \right)_I$$

substituting proper values of k and x

$$U_I = 2575 \left(\frac{\Delta t}{\Delta t_m} \right)_I$$

Measuring temperature difference across the plate thickness (Δt) and between the fluid bulks (Δt_m), overall heat transfer coefficients were calculated for each location.

Procedure

Copper-constantan thermocouples (1938 calibration, 24 B & S gage) were used for measuring the temperatures. Seventy-six thermocouples were soldered to the test plate forming thirty-eight pairs. A pair consisted of two thermocouples placed exactly opposite each other across the thickness of the plate. The temperature difference of a pair gave the value of Δt at that location. The positions of these pairs were arranged to obtain information for plotting U-contours.

In addition four thermocouples were placed one in each of the four ports for inlet and outlet of hot and cold milk to the test plate. These gave the end temperatures of the flowing fluids. Since the flow was completely turbulent and the width of the passage was very small (about 0.15 inches), the fluid temperature changed in a straight line along the length of the plate. Thus, Δt_m, the temperature difference of the fluid bulks, was calculated for each location.

A total of twenty tests were performed under similar operating conditions. The temperatures were measured manually with a precision potentiometer, read to .001 millivolt or approximately 0.05°F.

Contours of temperature and the overall heat transfer coefficients were then plotted over the plate area, Fig. 2 and 3.

Results

The inlet and outlet temperatures of hot pasteurized milk and cold raw milk, measured for the entire regenerator section yielded an overall effectiveness of 79 per cent.

The isotherms plotted for either side of the plate surface showed that the temperatures were approximately constant along the width for the main body of the heat exchanger area. Near the ports, however, large variations were seen which were due to the converging and diverging flow patterns. The temperatures varied in a straight line along the length of the plate.

The overall heat transfer coefficients varied between 300-800 B.t.u. per hr.-ft.^{2}-°F. over the area of the plate, giving an average value of 550 B.t.u. per hr.-ft.^{2}-°F. for the test plate. This was found to be within 15 percent of McKillop's results.[2] However, significant difference was observed when compared to values predicted by McAdams[3] or Peeples[4] empirical correlations for turbulent flow through clear channels. This is attributed to the corrugations or the turbulence promotors provided on the plate which create turbulence at very small flow rates, thus improving the heat transfer.

The contours of the overall heat transfer coefficient revealed that the U-values, in general, were at a maximum in the middle of the plate and decreased towards the edges. Along the length, however, the change was small and the values were nearly constant.

The contours of U-values suggested that the fluid velocities were approximately constant along the width (though somewhat higher in the middle compared to the sides) and that these patterns were identical along the length of the plate.

Conclusions

1. The plate surface temperatures were observed to be fairly constant along the plate width, except near the ports, but changed in a straight line along the length.

2. The local overall heat transfer coefficients ranged between 300-800 B.t.u. per hr.-ft.^{2}-°F. The average value for the plate was found to be 550 B.t.u. per hr.-ft.^{2}-°F.

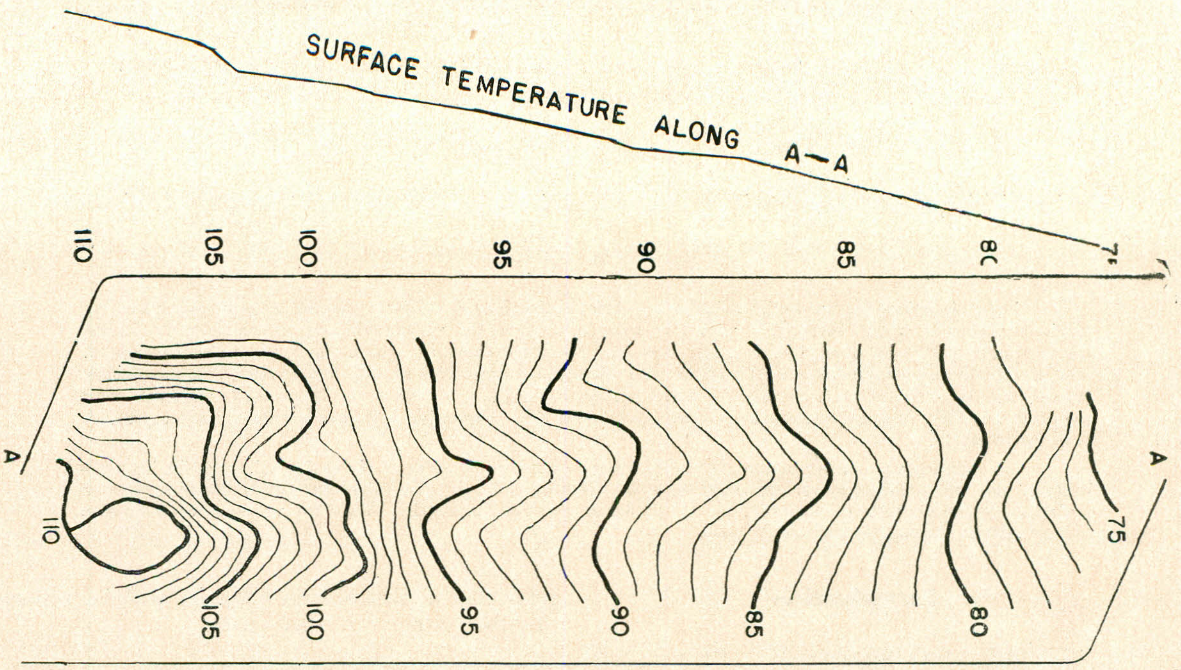

Fig. 3.—Temperature distribution on plate surface (hot side).

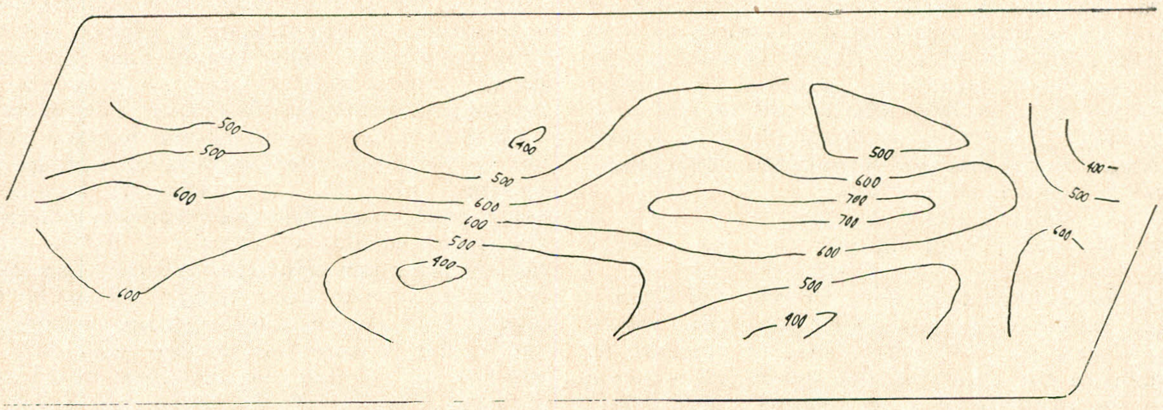

Fig. 2—U-plot on test plate.

3. The contours of the overall heat transfer coefficients showed that the values along the width were higher in the middle, compared to the sides. Little variation was seen along the length, however.

4. The overall heat transfer coefficient for the plate can be assumed constant for processes encountering small temperature change of the flowing fluids.

5. The overall effectiveness of the regenerator unit was found to be 79%.

References

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