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HEAT TRANSFER TO BOILING SKIMMILK

S. J. D. VAN STRALEN
Laboratory of Physics and Meteorology, Agricultural University, Wageningen, Netherlands

SUMMARY

The heat flux to boiling pasteurized skimmilk was determined by using a horizontal platinum heating wire, which served at the same time as a resistance thermometer.

A gradually increasing coagulation layer was precipitated on the wire at a constant heat flux of 10 cal sec^{-1} cm^{-2} under atmospheric pressure, which was attended by a rapid decrease in the coefficient of heat transfer.

The heat flux to skimmilk under a pressure of 10 cm Hg exceeded considerably that to water at the same temperature of the wire, and a higher maximum of nucleate boiling was found. Solutions containing small amounts of skimmilk in water showed similar high maxima.

METHOD AND APPARATUS

The rate of heat flow q from a heated wire to a boiling liquid is a function of $\Theta = t - T$, the difference in temperature between the heating surface and the bulk liquid. The curves representing the heat flux $\frac{q(\Theta)}{A}$, where A denotes the area of the heating surface, consist of three parts: the region of convection, in which no vapour bubbles are observed, the region of nucleate boiling, in which vapour bubbles are generated on special spots of the surface, and the region of filmboiling, in which a gradually increasing area of the surface is covered with a coherent layer of vapour. In the regions of convection and nucleate boiling the values of Θ are small or moderate, in contradistinction to the region of filmboiling, where Θ amounts to much higher values (v. WIJK, VOS and v. STRALEN, 1956).

The method described by MCADAMS (1948) has in principle been used to determine the heat transfer curves up to the maximum of nucleate boiling for pasteurized skimmilk, for water and for solutions containing small amounts of skimmilk in water, all at a pressure of 10 cm Hg. For that purpose a gradually increasing D.C. was passed through a horizontal platinum wire, of which a central portion was isolated as a test section by the use of thin potential taps. This section served as a heating surface and at the same time as a resistance thermometer. The heat flux and the temperature difference between wire and liquid were directly calculated from measurements of the potential drop across the test section and of the current, since the specific resistance of platinum is known as a function of temperature (BURGESS and LE CHATELIER, 1912).

The wire was connected in series with a manganin standard resistor. The potential drop across this resistor is directly proportional to the heating current. After reduction to suitable values by application of tapped shunts, this voltage and that across the wire were recorded on a potentiometer. The reference value of resistance was determined by passing a small current through the circuit while the wire was immersed in the boiling liquid.

The boiling vessel consisted of a glass cylinder with ground endfaces. A nickel plated brass cover ring and base were fastened by draw bars to the cylinder and neoprene rings were used for packing. A pertinax cover was provided with four nickel plated brass bars. The wire was stretched between two opposite bars, while the potential taps were attached to the other bars. A total reflux condenser was mounted on the cover plate and the boiling vessel was only partly filled with liquid, which was heated from below by a Bunsen flame to the boiling temperature desired. The combined action of a water jet pump and a Cartesian manostat insured then a constant vacuum.

RESULTS

Skimmilk at atmospheric pressure

A constant heat flow of 3.45 cal sec^{-1} was supplied to boiling skimmilk at atmospheric pressure. This value corresponded to an initial heat flux of 9.8 cal sec^{-1} cm^{-2} and insured nucleate boiling on the wire. The temperature of the wire increased rapidly, which was caused by a precipitation of coagulation

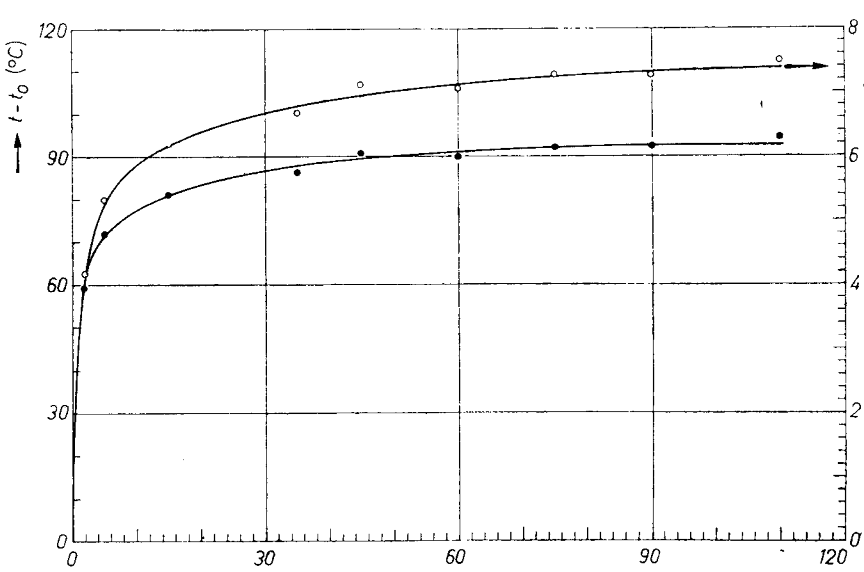

FIG. 1. INCREASE IN TEMPERATURE OF HEATING WIRE AND GROWTH OF COAGULATION LAYER AT A CONSTANT HEAT FLUX OF 10 cal sec^{-1} cm^{-2} TO BOILING SKIMMILK UNDER ATMOSPHERIC PRESSURE.
t_0 denotes the initial wire temperature and d the average thickness of the layer.

products on the heating surface. The precipitate consisted of a nearly solid substance, which was coloured yellowishly in this case only.

If a constant temperature t_0 of the gradually increasing exterior area of the coagulated layer is assumed, one can estimate the growth of this layer and its thermal conductivity, provided that the initial and the resultant wire diameters are measured.

The result is represented in Figure 1, where the increase in temperature and radius of the heating surface are shown. The thermal conductivity of the coagulated layer was found to be equal to 6×10^{-4} cal sec^{-1} cm^{-1} $°C^{-1}$ approximately. Obviously the layer acted fairly well as an insulator, and for this reason restriction had been made further to the determination of heat flux data at a pressure of 10 cm Hg.

Skimmilk and water at a pressure of 10 cm Hg

In Figure 2 (curve 1) the heat flux to boiling skimmilk at a pressure of 10 cm Hg ($T = 51.63$ °C) is shown as a function of the temperature difference between heating wire and liquid. This experiment had been repeated twice. For comparison the heat flux to boiling water ($T = 52.36$ °C) had also been determined at the same pressure (curve 3). This experiment was carried out previously with one of the same wires.

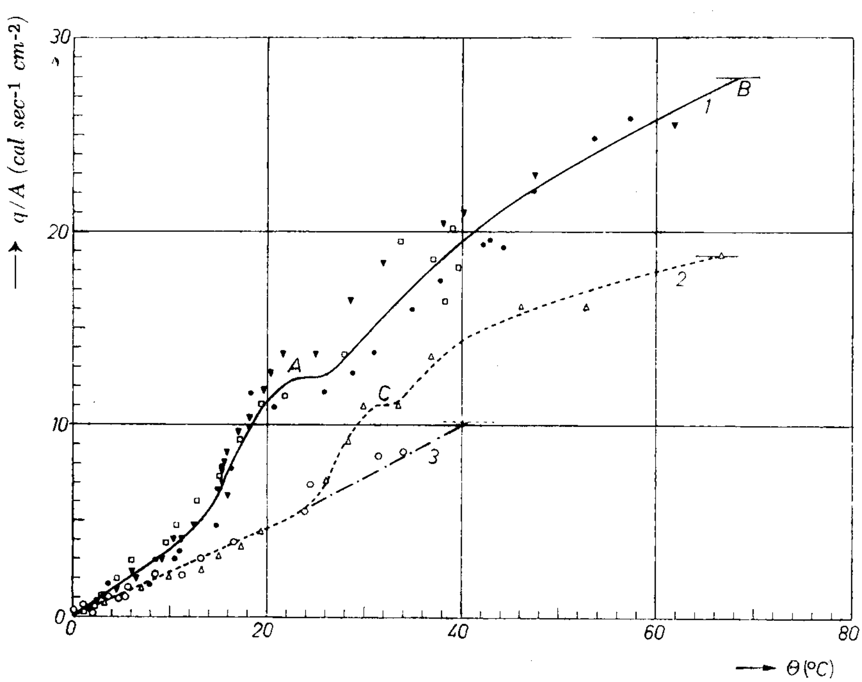

FIG. 2. HEAT FLUX FOR CONVECTION AND NUCLEATE BOILING TO SKIMMILK (CURVE 1), TO A SOLUTION CONTAINING 3.2 % SKIMMILK IN WATER (CURVE 2) AND TO WATER (CURVE 3) AS A FUNCTION OF TEMPERATURE DIFFERENCE BETWEEN HEATING SURFACE AND LIQUID AT A PRESSURE OF 10 cm Hg.

The temperature of the wire increased rapidly at point A (curve 1), when a value of 80 °C approximately was reached. This was probably caused by a suddenly commencing heat coagulation of proteins, contaminating the surface, whereas the gradually increased potential drop across the test section can only be held responsible for a continuous contamination.

The values of Θ, which had been determined in the region AB, can not be considered to be quite exact, since the reference value of resistance had also been increased. Several wires burned out in skimmilk at an average heat flux of 28 cal sec^{-1} cm^{-2}, when Θ was equal to 70 °C approximately. In case of water the wire passed into filmboiling at the much lower heat flux of 11 cal sec^{-1} cm^{-2} (curve 3).

3.2 % and 0.7 % skimmilk at a pressure of 10 cm Hg

With another wire the heat flux to a solution containing 3.2 % skimmilk in water ($T = 52.26$ °C) was determined (curve 2). This curve tallies quite satisfactorily with the curve for water, until at point C the curve shows a similar behaviour as in case of skimmilk.

With the object to ascertain that the range AB of curve 1 is really still in the region of nucleate boiling, the heat flux to a solution containing 0.7 % skimmilk in water was also studied. In this case the vapour bubbles could be observed, and a violent nucleate boiling took place on the heating surface, which was much more intense than at the maximum heat flux to water.

It may be worth noticing that rather stable foaming appeared at all concentrations of skimmilk investigated. Further the conclusion can be drawn from figure 2, that at a pressure of 10 cm Hg the heat flux $\frac{q}{A}$ and the coefficient of heat transfer $h = \frac{q}{A\,\Theta}$ for skimmilk exceed considerably the corresponding values for water, while a much higher maximum of nucleate boiling was found.

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