Considerable attention has been attributed to the heat stability of concentrated milk in dairy research due to the hazard of coagulation under heating conditions unconcentrated milk is able to withstand. Critical temperature-time conditions of the heat treatment without coagulation, especially under continuous heating conditions and the total solids content of the concentrate were unknown. In addition, undesired heat-induced structural changes in concentrated milk eventually leading to colloidal destabilisation of casein micelles and the subsequent coagulation process have not yet been fully understood. The rate determining steps of this reaction leading to coagulation could not be identified, yet. The elucidation of the underlying mechanisms of the coagulation process is complicated mainly because of the compositional complexity of milk.

Natural variations in the multi-component milk system and the interaction of constituents in heated milk made it difficult, on the one hand, to induce targeted changes and to observe specific effects of heat, i.e. to find correlations between changes made and their respective effects. Mainly the milk salts, especially calcium, and the physico-chemical state of proteins were considered as relevant components affecting heat-induced coagulation of milk and concentrated milk (Sommer and Hart 1919; Singh et al. 1995; Crowley et al. 2014; Crowley et al. 2015). However, milk proteins as polyelectrolytes could also be considered as part of the milk salt system as they will be affected by changes in pH, ionic strength, temperature, divalent cations, addition of phosphates, and citrates that also affect each other (Walstra et al. 1984). On the other hand, methods to assess heat stability of milk were mostly based on the visual observation of a single point in the coagulation process and mostly at a fixed temperature. A targeted variation of the heating temperature was only performed by Davies and White (1966) for unconcentrated milk. A tracking of the coagulation process to derive kinetic parameters for unconcentrated milk was performed by White and Davies (1966) and White and Sweatsur (1977) to study the kinetics of the reaction. Nieuwenhuijse et al. (1991) followed the course of coagulation of concentrated milk at different pH values, but focused on the shape of the flocs rather than on kinetics. An attempt to study the kinetics of the coagulation of concentrated milk had not yet been carried out.
9.1 Heat stability of concentrated milk

The subjective heat stability testing procedure at constant temperature as described in literature was used to some extent to study the temperature dependency of the heat coagulation time (HCT) by Davies and White (1966). From this approach, however, no information is obtained about the kinetics of heat-induced destabilisation of casein micelles, the reactions taking place, the course of the coagulation, and the extent of dissociation of casein from micelles. The objective test method can be regarded as superior with respect to the information obtained although it is much more time-consuming. This method was originally developed by White and Davies (1966) for unconcentrated milk to ascertain the validity of the subjective method. It could be shown that the visual determination of the onset of coagulation is relatively precise as heat-induced coagulation proceeds rapidly to form large protein aggregates after the initial lag-phase of complete stability, i.e. the HCT. However, it has to be born in mind that the coagulation time is an approximation to the actual sample stability due to the limited amount of coagulum to be formed for the visual detection of coagulation. A formal reaction kinetic model was proposed by White and Sweetsur (1977) for the coagulation process of unconcentrated milk when the initial lag-phase was neglected.

A very pronounced coagulation was also observed using the heat stability test as described in section 4.2, especially for concentrated milk. The higher the total solids content of the concentrate the more pronounced was the coagulum formation. In addition, slight variations in the temperature profile of the heat stability test markedly affected the coagulation time observed, especially when samples already coagulated during the come-up time to the final temperature. At first, the relationship between the coagulation temperature and time was uncertain. Therefore, these two parameters were recorded separately and taken both as a means to characterize the overall heat stability of the concentrates. Hence, a systematic approach to relate these two parameters was necessary.

The observation of the variation of the HCT with slight changes in the temperature-time profile, a lower heat stability of the concentrates with increasing total solids content, and results in literature suggested that the reactions in concentrated milk leading to coagulation can be described by kinetics. It was found that iso-effect lines for the visual coagulation of concentrated skim milk of different total solids content can be obtained as shown in Fig. 9-1 (Dumpler and Kulozik 2015). It is impossible to derive kinetic parameters by the visual determination of the coagulation point and the non-isothermal heat treatment in this batch heating system. Nevertheless, the relationship between the heat coagulation temperature and the corresponding coagulation times as a means to estimate the overall heat stability of CSM depending on its total solids content could be shown.

When we now consider the data obtained by the objective heat stability test of White and Davies (1966) and White and Sweetsur (1977), it is possible to state that the variable sample temperature, or better to say the variable rate constants, of the subjective heat stability test integrated over time until coagulation occurs gives a