Dynamic Modeling of Milk Acidification for Product Design and Process Control

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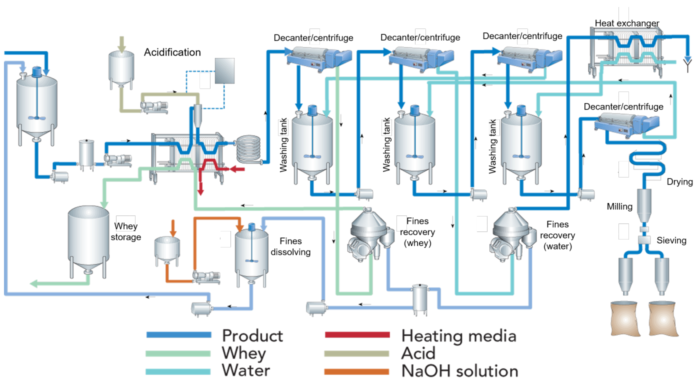
Introduction

In the production of many dairy products (*e.g.*, yoghurt) and dairy ingredients (*e.g.* caseinate), the coagulation of casein by the addition of acid is an important step for the performance of the downstream processing and product quality. Acidification proceeds with the addition of mineral acid to bring milk to a pH around 4.6, where casein precipitates.

The precipitation step determines the initial particle size and the formation of undesired components, such as calcium phosphate, which are important product quality parameters. Therefore, monitoring and regulating of acidification of milk protein systems is essential and becomes relevant to achieve consistent operation to deal with variations in milk. In order to assure a consistent operation, knowing the dynamics of the casein precipitation is of utmost importance. A good indicator to infer the dynamics can be pH.



Key Performance Indicators		
Casein content	Residual Ca^{2+}	Firmness
Particle size	Particle strength	

Figure 1: Casein production process, (The flowsheet is taken from [1])

Objective

Development of a dynamic model which describes the evolution of pH, minerals release and protein precipitations for control, monitoring and product development purposes.

Modeling Experiments

Table 1: Experiments at different aciditication times.

Total Acid Added A_{TOT} [ml]	Acidification Time t_{ACID} [min]
5.6	2.5
5.162	5
5.4	10
5.31	30
5.4	0

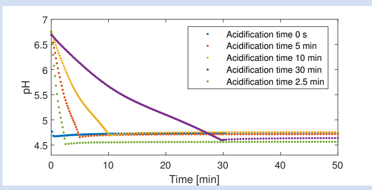


Figure 2: pH dynamics at different acidification times and 20°C.

Proposed Model Structure

During Acid Addition

$$\frac{dH^+}{dt} = \begin{cases} \frac{\partial pH}{\partial A}\frac{\partial A}{\partial t}H^+\ln(10), & \text{if } Q>0 \\ r_{H+}, & \text{if } Q=0 \end{cases} \quad (1)$$

$$\frac{dPr}{dt} = \frac{\partial Pr}{\partial H^+}\frac{\partial H^+}{\partial t} - \frac{1}{V}QPr \quad (2)$$

$$\frac{dPi}{dt} = \frac{\partial Pi}{\partial H^+}\frac{\partial H^+}{\partial t} - \frac{1}{V}QPi \quad (3)$$

$$pH = -0.0072A^3 + 0.1024A^2 - 0.7234A + 6.7844 \quad (4)$$

Buffering

$$\frac{dH^+}{dt} + \frac{H^+}{V}\frac{dV}{dt} - \frac{F^{in}_{H+}}{V} = -k_1\frac{r_{Pr}}{V} - k_2\frac{r_{Pi}}{V} - \frac{r_{Pe}}{V} \quad (5a)$$

$$\frac{dPr}{dt} + Pr\frac{dV}{dt} = \frac{r_{Pr}}{V} \quad (5b)$$

$$\frac{dPi}{dt} + Pi\frac{dV}{dt} = \frac{r_{Pi}}{V} \quad (5c)$$

$$\frac{dPe}{dt} + Pe\frac{dV}{dt} = \frac{r_{Pe}}{V} \quad (5d)$$

where the buffering rates r_{Pr}, r_{Pi}, r_{Pe} are functions of concentrations and parameters $r = \mathcal{F}(H^+, Pr, \theta)$.

Results

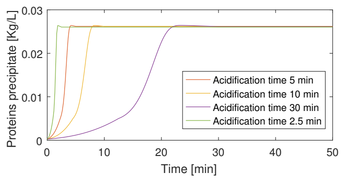


Figure 3: Proteins precipitate concentration estimation according to eq.2.

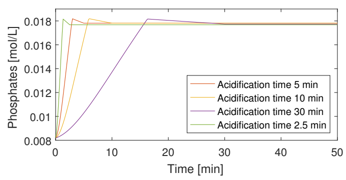


Figure 4: Phosphate concentration estimation according to eq.3.

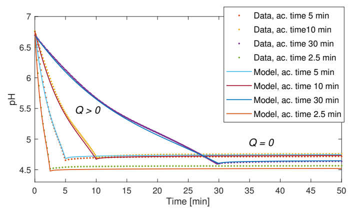


Figure 5: Comparison of the model predictions (eq.1) and the data.

Conclusions

The model shows good fit with the experimental data and the information in the literature. Furthermore, it has the potential to be used for dairy products and ingredients development in which acidity plays an important role.

Acknowledgement

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