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The Use of On-Line Sensors in Food Processing

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The objective of this research was to apply on-line continuous sensors in food processing, in particular in cheese and milk powder manufacture, in order to achieve higher quality, increased yields and reduced losses. This project focused on technologies for monitoring rheology-related parameters. Two on-line systems for monitoring curd firmness in cheesemaking have been deployed in commercial cheese plants with promising results.

Teagasc
The Science of Farming and Food

The Application of On-line Sensors and Novel Control Technologies for Food Processing
(The Use of On-Line Sensors in Food Processing)

Armis No. 4226

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Summary and Conclusions

In food processing there is a need to manufacture products of consistently high quality to stringent specifications from raw materials which may vary in their composition or physical properties. Hence food processing systems must be designed to detect and compensate for these changes. Where a food process is continuous, on-line sensing (which determines the state of a process in real time) is an ideal method to address this problem. For useful application, sensors must fulfil several requirements, e.g. ability to interface with plant monitoring/control systems, cleanability and stability with time and temperature. Development of new process control sensors for the food industry, in parallel with developments in process control technology, has the potential to increase the levels of process automation in the food industry.

The objective of this research was to apply on-line continuous sensors in food processing, in particular in cheese and milk powder manufacture, in order to improve process control, for example, by achieving higher quality, increased yields, reduced losses and less downgrading of product. This project focused on technologies for monitoring rheology-related parameters.

The main conclusions were as follows:

* *Seven systems for monitoring curd formation in cheesemaking were evaluated in the laboratory.*

* *Two on-line systems for monitoring curd firmness (hot-wire and NIR reflectance) have been deployed in a commercial cheese plant with promising results.*

* *Experimental results demonstrated that NIR reflectance / transmission probes have a potential for on-line application in cheesemaking. Despite the difference in scale, the commercial sensors compared well with the cheesemaker's observation of curd firming and look promising as an objective means of predicting curd cut time in an industrial cheese plan.*

* *A detailed knowledge of the rheological variation in cheese curd has been developed and a means of investigating factors which influence the rheology of cheese curd (e.g. effect of heat treatment or fortification of cheesemilk) has been determined.*

* *Technologies available for monitoring concentrate viscosity changes in the production of milk powder have been assembled at pilot scale, and initial trials have been encouraging. Further evaluation of the MTL plant to assess on-line performance, ruggedness and cleanability are planned.*

Research and Results

Sensing technologies for monitoring curd-forming processes.

In cheese manufacture the cutting of the coagulum is a key step in determining product quality and losses. Correct timing of the cutting operation with respect to the firming of the coagulum is necessary to minimise the losses of fat and curd fines. A sensor which monitors milk coagulation and compensates for fluctuations in temperature, enzyme activity and variations in milk composition would allow the coagulum to be cut consistently at an optimal condition, enabling higher yields to be achieved in combination with more consistent control of product moisture. In this project many technical options for sensing curd firmness were investigated, some of which sense viscosity-related changes during renneting of milk while others sense changes in optical properties in the course of aggregation of casein micelles *(Table 1)*.

Table 1. Range of sensors investigated for on-line monitoring of curd firmness

Type of sensor	Sensed parameter	Principle
Hot-wire	Viscosity	Convective heat transfer
NIR diffuse reflectance	Aggregation	NIR light is transmitted into the fluid via a fibre-optic probe, and the fraction reflected by the micelles is measured reflected.
Visible diffuse reflectance	Aggregation	(as above, but using visible light)
NIR transmission	Aggregation	The transmittance of NIR light through the fluid is measured.
Tuning fork vibration	Viscosity	The viscous damping effect is measured.
Torsional vibration	Viscosity	The viscous damping effect is measured.
Ultrasonics	Viscosity	Attenuation of ultrasonic vibration is measured.

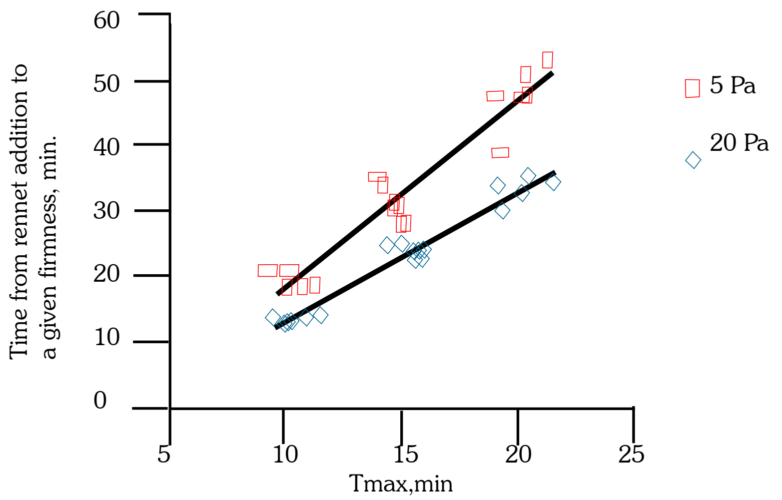
Gel time prediction using NIR reflectance

Trials were performed with reconstituted skim milk (3.0 - 3.7% protein) using a near infra red (NIR) reflectance probe in a 1 litre vessel to determine a gel time which was compared to the time required to reach a firmness for cutting the curd (i.e. time to reach 5 Pa or 20 Pa). The results showed that the time of curd-cutting could be predicted *(Fig. 1)*.

Renneting trials - comparison of hot wire, NIR reflectance and visible reflectance.

The performance of three on-line sensors (hot wire, NIR reflectance and visible reflectance) were compared in three different studies, one involving skim milk and two involving whole milk. In the first study, extra low heat stable skim milk powder (WPNI > 6) was reconstituted to a constant solids level and renneted under varying process conditions (pH 6.3, 6.5, 6.7; rennet concentration 54, 77, 100 g/kg milk; temperature 27, 31, 35°C). In this

Fig. 1. Firmness measurements by laboratory rheometer vs. NIR reflectance probe.



study the sensors were able to predict cutting time with an average deviation of 1.5 minutes, with good repeatability for replicates at the same conditions. This was achieved without having to incorporate any process conditions into the analysis. A 10% increase in rennet concentration was found to reduce the set-to-cut time by about 2 minutes, and this was equivalent to increasing the setting temperature by 1 degree Celcius . All three sensors detected these changes equally well.

In the second study, the effect of protein variation in milk was investigated by preparing a range of milks of different proteins (from 2.9% to 4.5%) from one batch of milk using ultrafiltration and renneting them under constant process conditions (pH 6.5, rennet concentration 77 g/kg milk, temperature 31°C). The average deviation in set-to-cut time determination was less than one minute but a protein concentration factor had to be included for the hot-wire and the visible diffuse reflectance probes *(but not for the NIR probe).*

The third study investigated seasonal effects on coagulation using milk from a cheese making plant and from a spring calving herd. The results showed that both the NIR and hot-wire probes followed varying trends and seasonal changes faithfully, whilst the visible diffuse reflectance probe did not. Under conditions of stable milk protein level a hot-wire system performed as well as a fibre-optic NIR reflectance system as a predictor of a curd-cutting point. However, where milk composition was varying the NIR system outperformed the hot-wire system. Both systems have a potential for on-line application in cheesemaking. *The sensors performed successfully over the range of conditions and milk composition.*

Renneting trial - comparison of six on-line sensors with laboratory rheometer

In order to measure the effect of protein level in milk on curd firming characteristics, and to investigate how well the different sensors followed curd firming under varying milk composition, such as found in the course of a season, the protein level in milk was adjusted

Fig. 2. Effects of protein on firming time, for three levels of rennet.

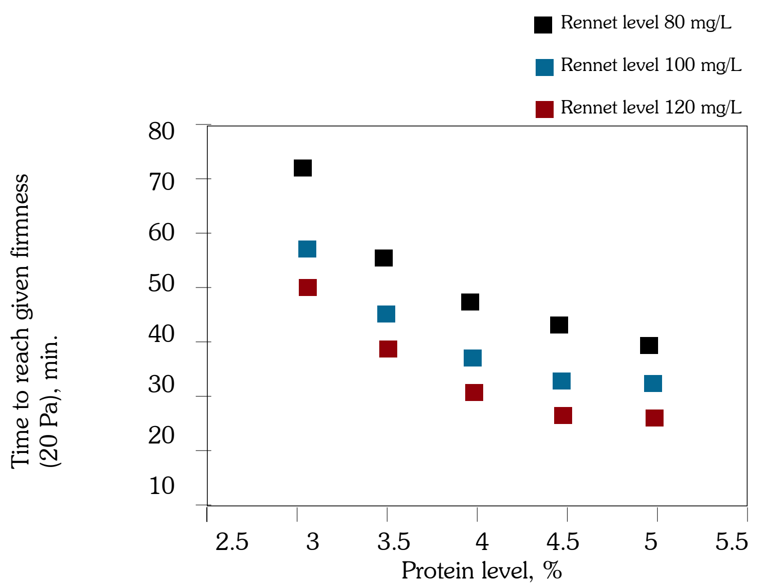
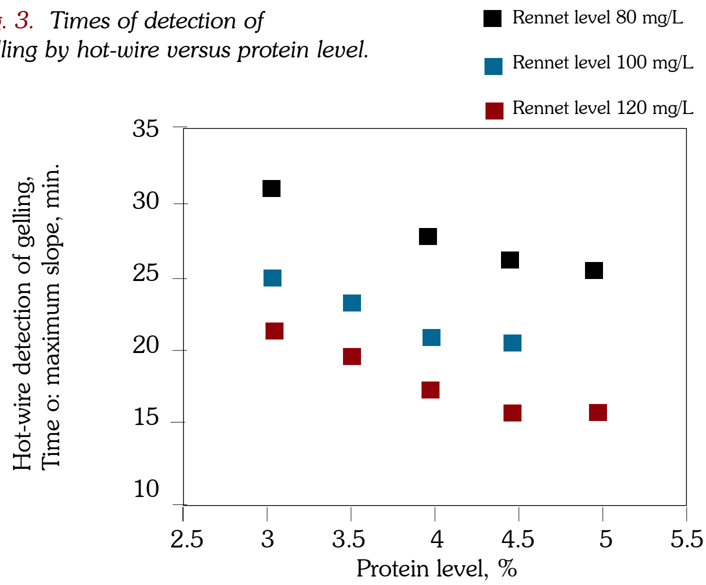


Fig. 3. Times of detection of gelling by hot-wire versus protein level.



by ultrafiltration, over the range 3 to 5% and renneted (3 levels). Six on-line sensors of coagulation [hot wire, NIR diffuse reflectance, NIR transmission (two sensors), Tuning fork vibration (two sensors) and torsional vibration] were compared with measurements of curd firmness using a laboratory rheometer. *Fig. 2* shows the effect of protein concentration on curd-firming rate, as determined by the rheometer. The corresponding detection times for the hot-wire and NIR sensors are shown in *Figs. 3* and *4.*

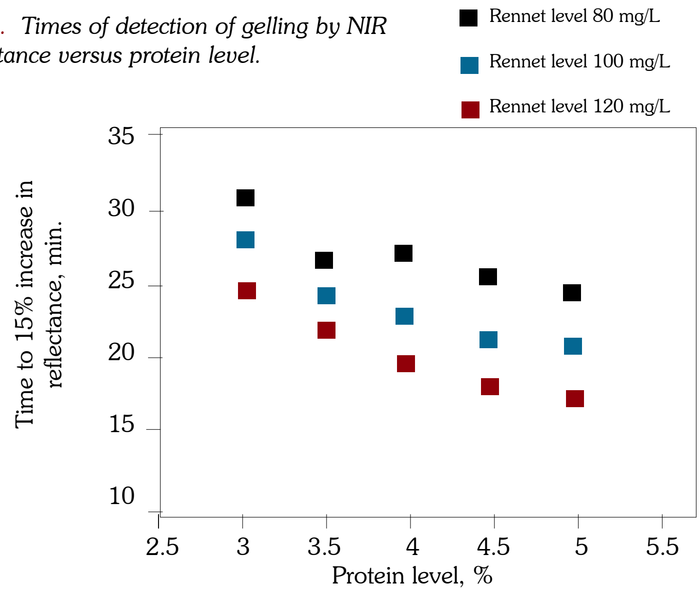
Ultrasonic system

Renneting trials were carried out with skim milk in which ultrasonic velocity and attenuation were measured at ultrasonic frequencies in the range 1 to 16 MHz. Strong correlation was obtained between ultrasonic attenuation and the response of the NIR diffuse reflectance probe. The magnitude of ultrasonic attenuation was greater at higher ultrasonic frequencies. No significant changes in ultrasonic velocity were observed during milk coagulation.

Prototype sensor systems for automation of the cheese manufacturing process, and trials under cheesemaking conditions

The coagulation profile of a laboratory scale sensor in a 1.5 litre vat was compared to that of an industrial design in a 15,000 litre vat using the same cheesemilk, starter, added CaCl2, rennet and clotting temperature in both vats (i.e. parallel trials) to assess scale-up behaviour. Three different cheese recipes, Leerdammer, Emmental and Blarney, were monitored and the response of the laboratory sensor differed from the industrial one by

Fig. 4. Times of detection of gelling by NIR reflectance versus protein level.



1.5 minutes, for a range of gel times from 10 to 20 minutes. A hot-wire probe was also installed on the cheese vat and the response of each sensor was compared with the cheesemaker's determination of cut-time. Out of 14 trials the NIR system gave a slightly better confidence level ($P<0.008$) in regression versus cheesemaker's observation than did the hot-wire system ($P<0.015$).

Technologies for on-line monitoring of viscosity variations in liquid concentrates including those encountered in milk powder manufacture.

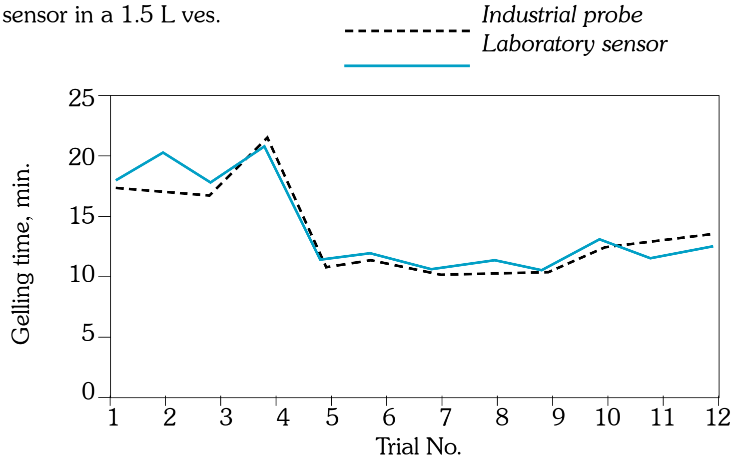
Use of sensors in spray drying

In the manufacture of milk powder and dried ingredients opportunities exist for improved quality control, reduced product loss and better energy utilisation through the development of suitable sensors, e.g. for monitoring on-line viscosity of concentrated milk.

With respect to on-line monitoring of viscosity of concentrates during spray drying a pilot-scale experimental rig was constructed where liquids were circulated continuously in a pipeline and viscosity readings were determined by on-line capillary, rotational and vibrational rheometer systems. This on-line equipment had a sanitary CIP-able design. Performance of these systems were assessed using a laboratory rheometer. The (non-Newtonian) rheology of some milk concentrates was characterised. All of the on-line systems performed well for Newtonian sucrose solutions yielding results that were comparable with the off-line rheometer control. The rotational and vibrational systems performed well on milk concentrates (non-Newtonian solutions) but longer sections of capillary tubing than were employed in this study would be required to facilitate accurate measurement of viscosities below 30 mPa.s.

Acknowledgment

Fig. 5. Comparison of times at which gelling was detected using an industrial NIR probe in a 15,000 L cheese vat and a laboratory NIR sensor in a 1.5 L ves.



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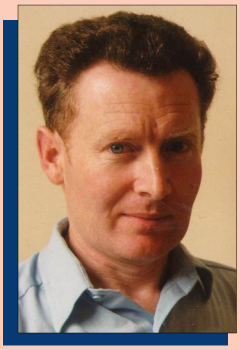

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