Improved Control in Dairy Processing

(On-line Sensor Control for Milk Powder and Cheese Manufacture)

Armis No. 4591 ISBN 1 84170 182 3 DPRC No. 42 August 2001

Project Team: Dr. Donal O'Callaghan (Leader), Dr. Daniela Schulz, Dr. Colm O'Donnell*, Mr. Arthur Duffy*, Mr. John Hade*, Mr. Vincent Howard*

**Agricultural & Food Engineering Dept., University College, Dublin*

The Dairy Products Research Center, Moorepark, Fermoy, Co. Cork.

Teagasc acknowledges with gratitude grant aid under the Food Sub-programme (Sub-Measure 3 (ii) - Institutional R&D) of the Operational Programme for Industrial Development. The Programme was managed by the Department of Agriculture and Food supported by EU and national funds.

This project demonstrated novel applications for on-line monitoring and control in milk powder and cheese manufacture to improve product quality consistency, increase yields and reduce losses.

Cover picture: Fibre optic probe installed in commercial cheese vat.

This document is also available for download in Acrobat PDF format.

Summary and Conclusions

In food processing, the quality of the end product is highly dependent on that of the raw material(s) used. Where raw material composition is variable, as in the case of seasonally produced milk, there are particular advantages in using sensors which determine the dynamic state of a process on-line and in real time. However, the complex flow characteristics of typical fluid foods, such as milk, during different stages in processing, call for robust and innovative sensor design. This project investigated the use of on-line sensors of rheological characteristics which can be measured during the manufacture of milk powder and cheese. The objective is to use on-line measurements to fine tune each process, so as to compensate for the variability of milk.

With 30% of Irish milk going into either whole- or skim-milk powder there is a strategic national interest in maximising the quality and efficiency with which these products are produced. The atomisation step in spray drying is central to the dehydration process and it is known that viscosity at this point has a crucial

effect on subsequent powder characteristics. However, the spray-drying environment poses a number of challenges to viscosity measurements.
Hence, this project set out to demonstrate one or more techniques which best meet the constraints of on-line viscosity monitoring in a milk powder plant.
Previous research on milk coagulation involved measurements of gelation/ curd formation in cheese-making at laboratory level. Such measurements, in conjunction with spectrophotometry and electrophoresis, led to major advances in the understanding of the mechanisms underlying milk coagulation, especially the proteolytic phase.
As cheese manufacture became increasingly mechanised and food safety issues became more critical, the commercial cheese factory began to operate around a series of enclosed vats with less opportunity for the cheesemaker to manually assess the gel strength. The scale of operation of modern plants, coupled with ever-increasing demands on quality control, have led to an interest in systems which monitor curd formation on-line.
In addition, simultaneous operation of a suite of cheese vats requires a time-based cycle with all vats filling and emptying in sequence to assist a fairly continuous flow of milk from the intake/pasteurising plant. Hence, an on-line device for measuring curd formation is highly desirable but it would need to be non-intrusive and cleanable-in-place.
Several techniques for monitoring curd formation have been applied at laboratory level and this project investigated the constraints in transferring such technology to modern commercial cheese manufacture.

Main Conclusions and Achievements

- This project demonstrated novel applications for on-line monitoring in milk powder and cheese manufacturing which make it possible to improve quality control in the manufacturing process, producing such benefits as more consistent product, increased yields and reduced losses.
- The project demonstrated novel on-line technology and led to improved technical know-how regarding the applications to Irish food processors. The research highlighted technical constraints in sensor application to dairy processes, which were overcome in the course of the project, by design modifications, e.g. various sanitary probe connections, low amplitude oscillation for cheese manufacture, and sanitary probe adapters for on-line probes in milk powder manufacture.
- In milk powder manufacture, it was shown that viscosity can be measured on-line as an integral and useful component of quality control. This opens the way to better control of the atomisation process, leading to reductions in product loss and energy consumption and better control of powder texture, bulk density and moisture. Less moisture variation would reduce the amount of downgrading and improve the over-run. On-line monitoring can also shorten start-up and shutting down times, when losses are highest, and can keep the plant running at near optimum conditions with minimum emissions.
- In cheese manufacture, low amplitude vibrating systems and fibre optic reflectance probes have each proved to be effective in determining the curd formation parameters of relevance to cheese-making in an Irish context, faced with wide seasonal variations in milk quality.

Research and Results

Milk Powder Manufacture

Previous research, including research at Moorepark and University College Dublin in the 1970s and `80s and more recently (see DPRC No. 23), has shown that the measurement of viscosity of concentrated milk is quite a challenging task due to its non-Newtonian flow properties and age-thickening characteristics and the presence of suspended solids and gases, all of which contribute potential sources of error, depending on the technique of viscosity measurement. Exposure to hostile process conditions, such as plant vibrations, fouling, cleaning agents, dust, etc., pose additional challenges in the engineering of on-line probes in food process plants.

The ideal design should facilitate cleaning-in-place with only minimal possibility of fouling, quick response time and good sample renewal to ensure that any measurement obtained is representative. It is essential that a probe meet sanitary requirements, such as the elimination of dead spaces where microorganisms could propagate. As some atomisation systems work with nozzles at high pressure, the appropriate viscosity measurement system may depend on atomisation type.

Research with rotational-type viscometers showed that the latter have some limitations in a dairy processing context which partly explains their poor uptake in milk powder plants. More recently several new viscometry techniques have been suggested or offered, including capillary, rotational and vibrational techniques.

In the course of this project, a thorough investigation of viscosity-measurement systems for use in milk powder manufacture was carried out, by means of literature surveys, commercial enquiries and liaison with researchers in the area. Seven on-line viscometers were sourced and laboratory trials were carried out using a viscosity test rig. Three on-line viscometers were selected for further evaluation at industrial scale. These comprised two types of vibrating probe and a sliding piston probe.

Viscosity of concentrated milk was measured on-line in a commercial evaporator. Comparison was made between on-line measurements of viscosity, specific gravity and off-line measurements of total solids. Analysis carried out highlighted the potential for increasing the level of milk concentration in the evaporator without exceeding the desired viscosity limit when either the preheat treatment was high or the protein-to-lactose ratio was low.

A model-based predictive control strategy was developed for a four-effect evaporator and process response to set-point changes in solids level, flow and temperature of concentrate product were simulated. Such a control strategy may be exploited in the longer term, e.g. in a context of higher energy costs.

Three on-line viscometers (a torsional-mode vibrating probe, a transverse-mode vibrating probe and a translational viscometer) were installed in a dairy evaporator in a plant where a range of whole milk powders are manufactured. Viscosity was monitored on-line at two points in the process, namely (i) ex-evaporator (before balance tank), and (ii) pre-atomiser (before concentrate heater) see Fig.1.

The range of products covered regular, low and high density whole-milk powder.

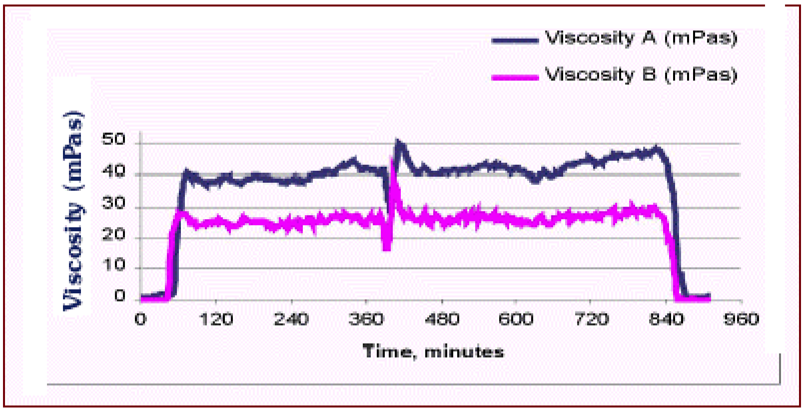

Fig. 1. Trend showing viscosity measured on-line at two points in the process during manufacture of whole-milk powder. Viscosity A was measured ex-evaporator using a vibrating rod in transverse mode. Viscosity B was measured between the concentrate heater and the atomiser using a vibrating rod in torsional mode.

It can be observed that viscosity varies by as much as 50% from the steady-state value. Wide variations were evident during the run.

On-line viscosity measurements were complemented with off-line measurements of viscosity and milk composition and on-line measurements of specific gravity, yielding a database of performance data over a range of products and composition. Typical trends of viscosity and specific gravity measured online using two different viscometers are shown in Fig. 2 & 3.

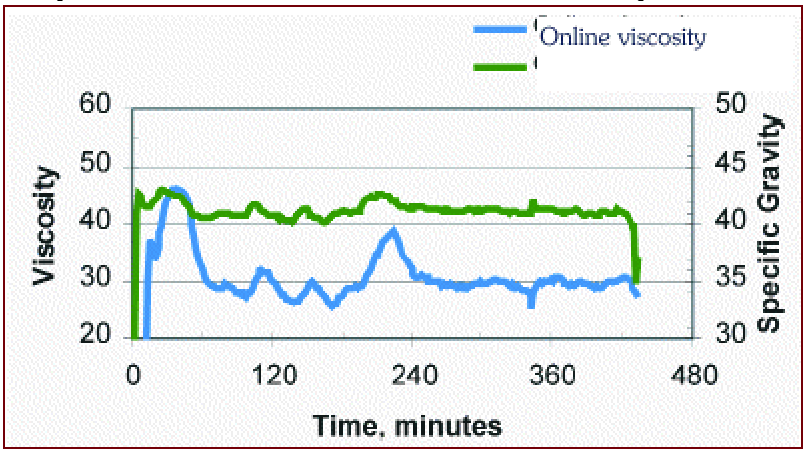

Fig. 2. Trend showing viscosity and specific gravity measured on-line during manufacture of whole-milk powder. Viscosity was measured using a vibrating rod in torsional mode. Specific gravity was measured using vibrating U-tube densitometer.

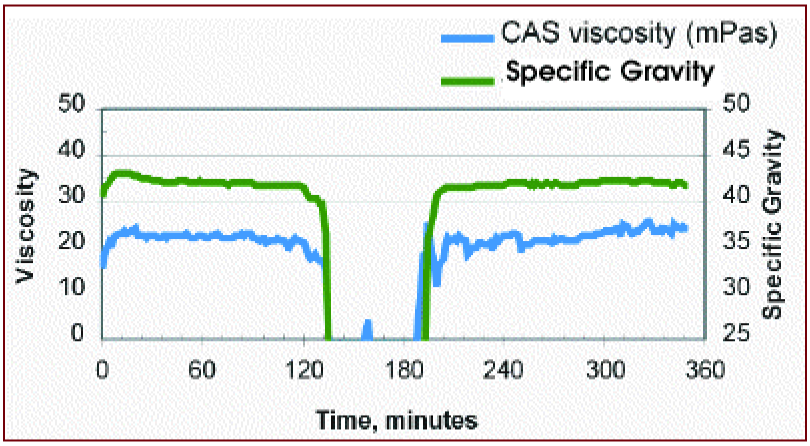

Fig. 3. Trend of viscosity measured on-line using a sliding piston sensor and specific gravity measured on-line using vibrating U-tube. The trend covers a period including some plant down-time.

The systems currently available to the Irish dairy industry for on-line viscosity monitoring are listed in Table 1. There were some technical difficulties with the operation of the SPC model sliding piston viscometer supplied by CAS whereby it did not work at a pressure of 5 bar. However, the design has been upgraded subsequent to our research project and is now specified to operate at 70 bar and has new features to eliminate dead spaces and has been given AAA approval. Torsional vibration gave the most trouble-free performance of those systems evaluated for monitoring viscosity. Its advantages include high immunity to plant vibration, ease of cleaning and low maintenance requirement, having no moving parts.

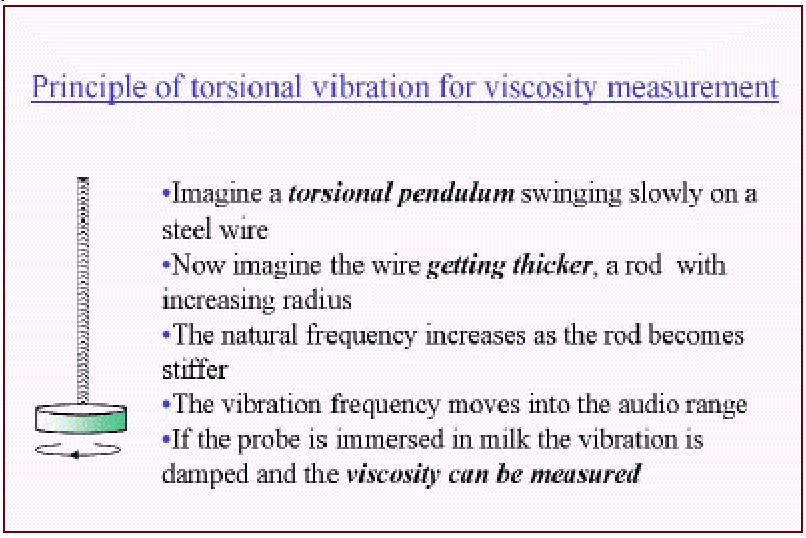

Image: Principle of torsional vibration for viscosity measurement

Table 1: On-line viscosity monitoring systems for use in milk powder manufacture.

Instrument	Principle	Overall Rating	Supplier
Sofraser	Low-frequency transverse vibration	* * *	Sofraser S.A. Villemandeur, 47500 France
ViscoLite	Torsional vibration	* * * *	Hydramotion Ltd. New York House, 1 York Rd. Ind. Park, Malton, N.Yorks., England YO17 0NW
Nametre	Torsional vibration	(not evaluated)	Nametre 25 Wiggins Avenue, Bedford, MA. 01730 U.S.A.
Solartron	Transverse vibration	*	Solartron Ltd. Victoria Road, Farnborough, Hampshire, England GU14 7PW
Cambridge AppliedSystems (SPC model)	Sliding piston	* * *	Carl Stuart Ltd. Unit 20/21, Town Yard Business

			Park, Leek, Staffordshire, England ST13 8BF
Brookfield STT-100® Sanitary Viscometer	Rotational	***	Brookfield Engineering, 11Commerce Boulevard, Middleboro, MA .02346 U.S.A.
Micromotion	Pressure drop	**	Fisher-Rosemount Ltd Flow Division, Horsfield Way, Bredbury Ind. Estate, Bredbury, Stockport, England SK6 2SU

Cheese Manufacture

In cheese-making, the coagulum needs to be cut when it has become sufficiently firm to form discrete particles, which expel whey without fragmenting. For this reason, the moment of curd cutting occurs some time later than the point of gelation. This implies a need to measure the firmness of a gel as it forms and up to the point where it is ready to synerese.

A review of research on the detection of milk coagulation revealed that a variety of techniques had been tried. Early techniques involved moving plungers or diaphragms which sensed resistance of coagulum to movement. However, these suffered from the disadvantage that the movement tended to disrupt the gel as it formed and thus interfered with the measurement of gel elasticity. While such devices proved highly useful for research on cheese-making, their use was confined to laboratory work because of intrusiveness in a cheese vat.

A more successful and less intrusive technique, known as the hot wire, was developed. It was based on the measurement of heat transfer from a heated probe and the fact that heat transfer coefficient decreases during the change from a liquid to a gel state. Several types of ultrasonic, vibrational, dielectric and, more recently, fibre-optic probes have also been experimented with.

The take-up of such systems in the dairy industry has varied from country to country and has been modest overall, with more take-up in Japan and the U.S.A. and rather less in Europe. One reason given by cheese manufacturers for not installing an on-line system in their plants, even where they see a role for such a system, is a perceived need for research on the performance and benefit of the systems that are offered.

In a preliminary phase of this project, laboratory trials were carried out in which a wide range of on-line probes were used to detect milk coagulation. The range of techniques included hot wire, vibrating probes and a variety of optical probes, some of which employed a light reflectance technique and others which employed light transmission through the milk (Fig. 4).

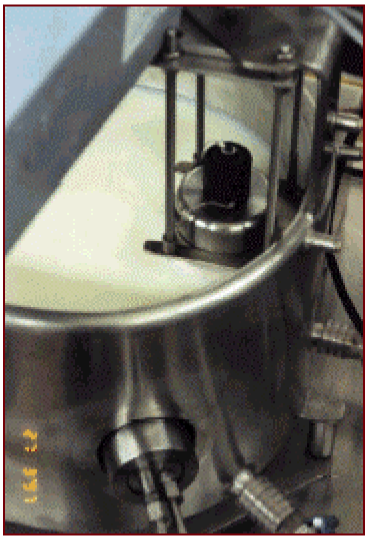

Fig. 4. Laboratory cheese vat fitted with combination of probes.

It was shown that the inflection point of the hot wire correlated best with the rheometric gel point and cutting time over a range of rennet levels. However, the hot wire is not suited to a variable protein environment, as protein has a large effect on curd firming rate but only a minor effect on the time at which a gel begins to form, which is what the hot wire measures.

Two on-line probes, namely, a hot wire and an optical probe, were selected from the laboratory trials and were installed on a vat in a commercial cheese factory. One of those probes is shown in an installed position in Fig. 5. Their performance was evaluated over two cheese-making seasons. In addition, off-line measurements were made with two other vibrational probes.

In the factory trials, the optical and vibrational sensors detected a decreasing curd firmness at the end of the season. Large variations in gel times (ca. 10 min) and set-to-cut times were detected during the season; with all sensors showing the same trend. The effect of milk seasonality was confounded by other uncontrolled variables (heat treatment, temperature, pH and rennet type).

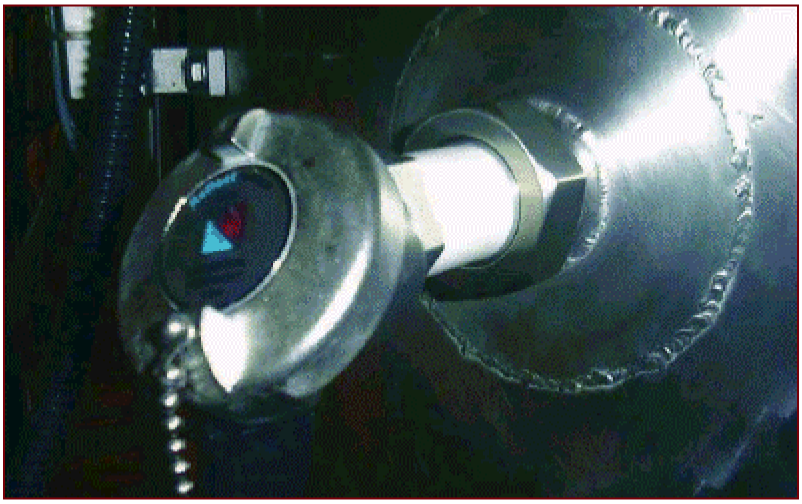

Fig. 5. Fibre optic probe installed in cheese vat.

This shows the value of on-line measurement, since it has not been possible to predict curd firmness in a commercial cheese-making situation from off-line measurements due to the interactive effects of so many variables.

In summary, fibre-optic reflectance probes and ultra low amplitude vibration were shown to be effective at measuring curd firming over a range of protein level, pH and temperature. The hot wire measured a very accurate gel point, but was not so accurate in predicting curd cutting point.

When protein level in milk was varied by addition of phosphocasein, set-to-cut time was measured most accurately by low-amplitude vibration ($R2 = 0.92$), followed by near-infrared reflectance ($R2 = 0.87$),
The techniques which are currently available commercially for monitoring curd formation in cheese-making are shown in Table

Table 2: On-line monitoring systems used to detect milk coagulation during cheese-making.

Instrument	**Principle**	**Overall rating**	**Supplier**
Sofraser	Low-frequency transverse vibration	**	Sofraser S.A. Villemandeur, 47500 France
Nametre	Torsional vibration	(not evaluated)	Nametre 25 Wiggins Avenue, Bedford, MA. 01730 U.S.A.
ViscoLite	Torsional vibration	***	Hydramotion Ltd. New York House, 1 York Rd. Ind. Park, Malton, N.Yorks., England YO17 0NW
Coagulometre	Hot wire	**	AGRIYORK 400 5 Lockwood Court, Market Place, York England Y042 2QW
CoAguLite	Fibre-optic NIR diffuse reflectance	****	Reflectronics Inc 3009 Montavista Rd, Lexington, Kentucky, U.S.A.
NIR Systems	Reflectance spectroscopy	(not evaluated)	Foss Ireland, Ltd. Sandyford Ind. Estate, 19 Corrig Road, Foxrock, Dublin 18, Ireland
TxPro	NIR transmission	**	Zellweger Analytics Ltd. 4 Stinford Road, Nuffield Industrial Estate, Poole, England BD17 0RZ
Gelograph-NT	NIR transmission	**	Gel Instrumente Boehnirainstr. 13, Thalwil CH 8800 Switzerland

Publications

O'Callaghan, D.J., O'Donnell, C.P. and Payne, F.A. (1999) A comparison of on-line techniques for determination of curd setting time using cheesemilks under different rates of coagulation. Journal of Food Engineering, 41(1) 43-54.

O'Callaghan, D.J., O'Donnell, C.P. and Payne, F.A. (1999). Effect of protein content of milk on the storage and loss moduli in renneting milk gels. Journal of Food Process Engineering, 22, 249-261.
O'Callaghan, D.J., O'Donnell, C.P. and Payne, F.A. (2000). On-line Sensing Techniques for Coagulum Setting in Renneted Milks. Journal of Food Engineering, 43 (3) 155-165.
Cullen, P.J., O'Donnell, C.P. and O'Callaghan, D.J. (2000). Process viscometry for the food industry. Trends in Food Science and Technology, Vol 11, Issue 12, pp. 451-457.
Mertens, B.J.A., O'Donnell, C.P. and O'Callaghan, D.J. (2001). Modelling near infrared signal for on-line monitoring in cheese manufacture. Journal of Chemometrics (In press).
O'Callaghan, D.J., Mulholland, E.P., Duffy, A.P., O'Donnell, C.P. and Payne, F.A. Evaluation of hot wire and optical sensors for on-line monitoring of curd firmness during milk coagulation. Irish Journal of Agricultural and Food Research (In press).
For further information, please contact
Dr. Donal O'Callaghan