11
Process Control In Food Processing

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11.1
Introduction

Process control is an integral part of modern processing industries; and the food processing industry is no exception. The fundamental justification for adopting process control is to improve the economics of the process by achieving, amongst others, the following objectives: (1) reduce variation in the product quality, achieve more consistent production and maximise yield, (2) ensure process and product safety, (3) reduce manpower and enhance operator productivity, (4) reduce waste and (5) optimise energy efficiency [1, 2].

Processes are operated under either steady state, i.e. process conditions do not change, or unsteady state conditions, process conditions depend on time. The latter occurs in most real situations and requires control action in order to keep the product within specifications. Although there are many types of control actions and many different reasons for controlling a process, the following two steps form the basis of any control action:

1. accurate measurement of process parameters;
2. manipulation of one or more process parameters using control systems in order to alter or correct the process behaviour.

It is essential to note that a well designed process ought to be easy to control. More importantly, it is best to consider the controllability of a process at the very outset, rather than attempt to design a control system after the process plant has been developed [1].

11.2
Measurement of Process Parameters

As mentioned earlier, accurate measurement of the process parameters is absolutely critical for controlling any process. There are three main classes of sensors used for the measurement of key processing parameters, such as tempera-

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ture, pressure, mass, material level in containers, flow rate, density, viscosity, moisture, fat content, protein content, pH, size, colour, turbidity, etc. [3]:

- Penetrating sensors: these sensors penetrate inside the processing equipment and come into contact with the material being processed.
- Sampling sensors: these sensors operate on samples which are continuously withdrawn from the processing equipment.
- Nonpenetrating sensors: these sensors do not penetrate into the processing equipment and, as a consequence, do not come into contact with the materials being processed.

Sensors can also be characterised in relation to their application for process control as follows [3]:

- Inline sensors: these form an integral part of the processing equipment, and the values measured by them are used directly for process control.
- Online sensors: these too form an integral part of the processing equipment, but the measured values can only be used for process control after an operator has entered these values into the control system.
- Offline sensors: these sensors are not part of the processing equipment, nor can the measured values be used directly for process control. An operator has to measure the variable and enter the values into a control system to achieve process control.

Regardless of the type of the sensor selected, the following basic characteristics have to be evaluated before using it for measurement and control: (1) response time, gain, sensitivity, ease and speed of calibration, (2) accuracy, stability and reliability, (3) material of construction and robustness and (4) availability, purchase cost and ease of maintenance.

Detailed information on sensors, instrumentation and automatic control for the food industry can be obtained from references [4, 5].

11.3 Control Systems

Control systems can be of two types: manual control and automatic control.

11.3.1 Manual Control

In manual control, an operator periodically reads the process parameter which requires to be controlled and, when its value changes from the set value, initiates the control action necessary to drive the parameter towards the set value.

Fig. 11.1 shows a simple example of manual control where a steam valve is adjusted to regulate the temperature of water flowing through the pipe [3].

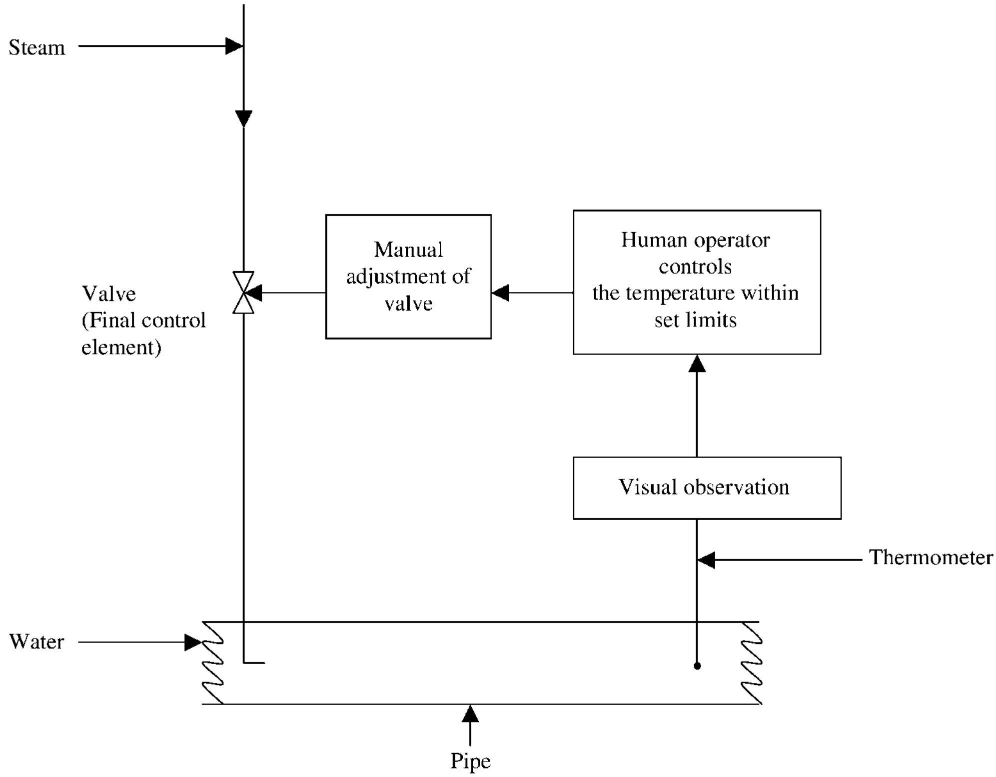

Fig. 11.1 A simple example of manual control; from [3].

An operator is constantly monitoring the temperature in the pipe. As the temperature changes from the set point on the thermometer, the operator adjusts the steam valve, i.e. either increases or decreases its flow, in order to get the temperature in the pipe back to the set point. Further action may be required if the temperature does not return to the set point within a reasonable time.

It is clear that the success of manual control operation depends on the skill of individual operators in knowing when and how much adjustment to make. Therefore, manual control may be used in those applications where changes in the manipulated parameter cause the process to change slowly and by a small amount. This is possible in plants where there are few processing steps with infrequent process upsets and the operator has sufficient time to correct before the process parameter overshoots acceptable tolerance. Otherwise, this approach can prove to be very costly in terms of labour, product inconsistencies and product loss.

11.3.2 Automatic Control

In automatic control, the process parameters measured by various sensors and instrumentation may be controlled by using control loops. A typical control loop consists of three basic components [3]:

- Sensor: the sensor senses or measures process parameters and generates a *measurement signal* acceptable to the controller.
- Controller: the controller compares the measurement signal with the set value and produces a *control signal* to counteract any difference between the two signals.
- Final control element: the final control element receives the control signal produced by the controller and adjusts or alters the process by bringing the measured process property to return to the set point, e.g. liquid flow can be controlled by changing the valve setting or the pump speed.

An automatic control system can be classified into four main types:

- on/off (two position) controller
- proportional controller (P-controller)
- proportional integral controller (PI controller)
- proportional integral derivative controller (PID controller).

11.3.2.1 On/Off (Two Position) Controller

This is the simplest automatic controller for which the final control element, e.g. valve, is either completely open or at maximum, or completely closed or at minimum. There are no intermediate values or positions for the final control element. Thus, final control elements often experience significant wear, as they are continually and rapidly switched from open to closed positions and back again. To protect the final control element from such wear, on/off controllers are provided with a *dead band*. The dead band is a zone bounded by an upper and a lower set point. As long as the measured process parameter remains between these set points, no changes in the control action are made. On/off controllers with a dead band are found in many instances in our daily lives: home heating system, oven, refrigerator and air conditioner. All these appliances oscillate periodically between an upper and lower limit around a set point. Fig. 11.2 illustrates the action of the control system.

It is interesting to note from the figure that the use of dead band reduces the wear and tear on the final control element, but amplifies the oscillations in the measured process parameter. Such controllers have three main advantages: (1) low cost, (2) instant response and (3) ease of operation. However, it is important to ascertain that the upper and lower limit values are acceptable for a specific process. The main disadvantages of this type of control action are: (1) it is not suitable for controlling any process parameter likely to suffer large sudden deviations from the set point and (2) the quality of control is inferior to the continuous controller.

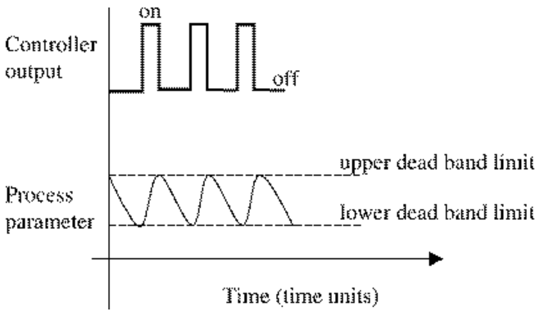

Fig. 11.2 Action of an on/off controller with dead bands; from [6].

11.3.2.2 **Proportional Controller**

The P-controller is one of the most commonly used controllers; and it produces an output signal to the final control element that is proportional to the difference between the set point and the value of the measured process parameter given by the sensor (this difference is also known as controller error or offset). Mathematically, it can be expressed as:

$$COS_{(t)} = COS_{(NE)} + K_C E_t \tag{11.1}$$

where $COS_{(t)}$ is the controller output signal at any time *t*, $COS_{(NE)}$ is the controller output signal when there is no error, K_C is known as the *controller gain* or *sensitivity* (controller tuning parameter) and E_t is the controller error or offset. The proportional controller gain or sensitivity (K_C) can also be expressed as:

$$K_C = \frac{100}{PB} \tag{11.2}$$

where PB is known as the proportional band, which expresses the value necessary for 100% controller output. The proportional controller gain (K_C), through the value of PB, describes how aggressively the P-controller output will move in response to changes in offset or controller error (E_t). When PB is very small, K_C is high and the amount added to $COS_{(NE)}$ in Eq. (11.1) is large. The P-controller will therefore respond aggressively like any simple on/off controller, with no offset, but a high degree of oscillations. In contrast, when PB is very high, K_C is small and the controller will respond sluggishly, with reduced oscillations, but increased offset. Thus, K_C through PB can be adjusted for each process to make the P-controller more or less active by achieving a compromise between degree of oscillations and offset. The main disadvantage of the P-controller is the occurrence of the offset, while its key advantage is that there is only one controller tuning parameter: K_C. Hence, it is relatively easy to achieve a best final tuning. Fig. 11.3 shows a step set point change under a P-controller for two different K_C values [6].

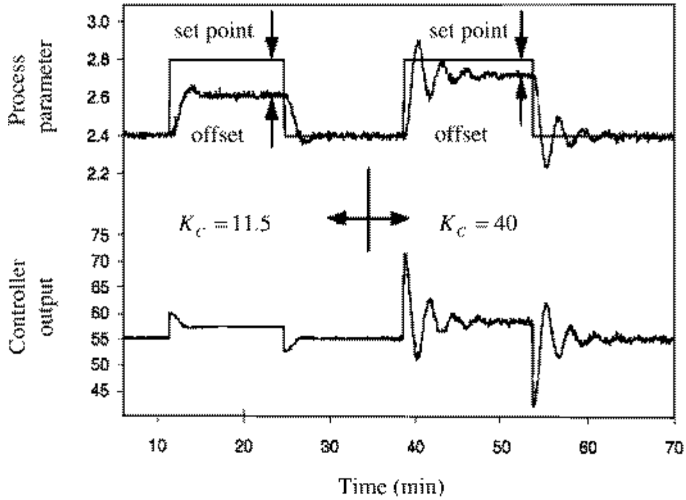

Fig. 11.3 P-controller with two different K_c values; from [6].

11.3.2.3 **Proportional Integral Controller**

The PI controller produces an output signal to the final control element which can be mathematically expressed as:

$$COS_{(t)} = COS_{NE} + K_C E_t + \frac{K_C}{\tau_I} \int E_t dt \quad (11.3)$$

where τ_I is a tuning parameter called the *reset time*; and the remaining notations are explained under Eq. (11.1). The integral term continually sums the controller error and its history over time to reflect how long and how far the measured process parameter has deviated from the set point. Thus, even if a small error persists over a long duration of time, the effects will add up. However, according to Eq. (11.3), the contribution of this integral term depends on the values of the tuning parameters K_C and τ_I. It is evident from Eq. (11.3) that higher values of K_C and lower values of τ_I will increase the contribution of the integral term.

Fig. 11.4 shows a typical PI controller response. It is clear from the case considered in the figure that, from 80 min onwards, E_t is constant at zero, yet the integral of the complete transient has a final residual value [obtained by subtracting A_2 from the sum (A_1+A_3)]. This residual value, when added to $COS_{(NE)}$, effectively creates a new overall $COS_{(NE)}$ value, which corresponds to the new set point value.

The consequence of this is that integral action enables the PI controller to eliminate the offset, which is the key advantage of the PI controller over a P-controller. However, it is important to note that in a PI controller, two tuning parameters interact and it is difficult to find the 'best' tuning values once the controller is placed in automatic mode. Moreover, a PI controller increases the oscillatory behaviour, as shown in Fig. 11.4.

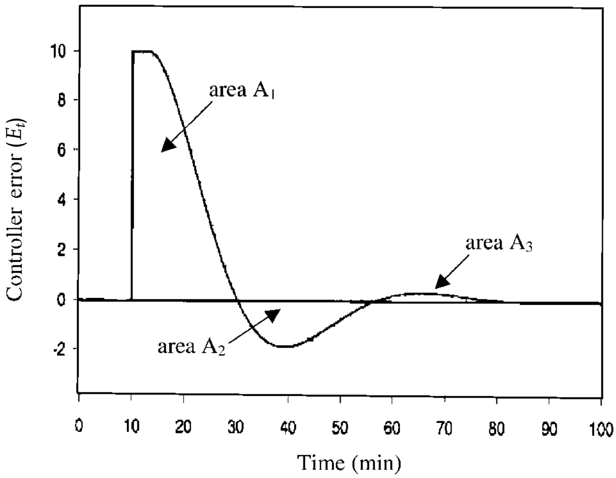

Fig. 11.4 PI controller – integral of error continually increases and decreases with time; from [6].

11.3.2.4 **Proportional Integral Derivative Controller**

In line with the PI controller, the PID controller produces an output signal to the final control element which can be expressed as:

$$COS_{(t)} = COS_{(NE)} + K_C E_t + \frac{K_C}{\tau_I} \int E_t dt + K_C \tau_D \frac{dE_t}{dt} \tag{11.4}$$

where τ_D is a new tuning parameter called the *derivative time*; and the remaining notations are already explained above. Higher values of τ_D provide a higher weighting to the fourth, i.e. derivative, term which determines the rate of change of the controller error (E_t), regardless of whether the measurement is heading towards or away from the set point, i.e. whether E_t is positive or negative. This implies that an error which is changing rapidly will yield a larger derivative. This will cause the derivative term to dominate in determining $COS_{(t)}$, provided K_C is positive. Fig. 11.5 shows a situation where the derivative values are positive, negative and zero (when the derivative term momentarily makes no contribution to the control action; note that the proportional and integral terms definitely influence at that point in time).

The major advantage of the PID controller, i.e. the introduction of the derivative term, is that it modifies the drawback of the PI controller: it works to decrease the oscillating behaviour of the measured process parameter. A properly tuned PID controller action can achieve a rapid response to error (proportional term), offset elimination (integral term) and minimise oscillations (derivative term). The key disadvantage of the PID controller is that it has three tuning parameters, which interact and must be balanced to achieve the desired controller performance. Just as in the case of the PI controller, the tuning of a PID controller can be quite chal-

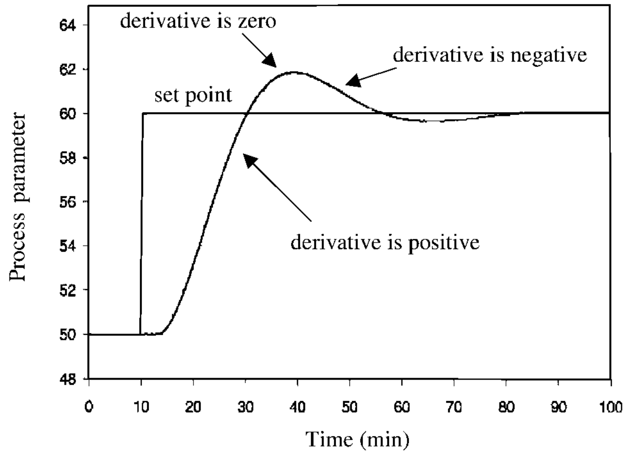

Fig. 11.5 PID controller – positive, negative and zero derivative values; from [6].

lenging, as it is often hard to determine which of the three tuning parameters is dominantly responsible for an undesirable performance.

To summarise, in all the above control actions, there are one or more parameters to be set when the controller is installed. However, it is most likely that the process information will be insufficient to give best values for these variables. Most control loops are therefore capable of becoming unstable and potentially result in serious consequences. Formal procedures are therefore necessary to arrive at the right controller settings. A number of procedures and techniques, each with their own advantages and disadvantages, have been developed over the years for *single* and *multivariable* control [7, 8].

A range of mathematical concepts have been applied in order to seek improvements in control quality. These are generally known as *advanced control* and include parameter estimation, fuzzy logic [9] and neural networks [10]. Without going into any further details, we will now consider how process control is implemented in modern food processes.

11.4 Process Control in Modern Food Processing

Control applications in food processing, according to McFarlane [1], can be discussed in the context of three categories of products: (1) bulk commodity processing, e.g. grain milling, milk, edible oil, sugar and starch production, where control is arguably most advanced, (2) manufactured products, e.g. pasta, cheese, in-container and aseptically processed products, and (3) products which have been subjected to processing methods essentially designed to retain their original structure, e.g. meat, fish, fruits and vegetables. Regardless of the nature of the products, process control in food processing has moved on from just attempting to control single variables, e.g. level, temperature, flow, etc., to systems which ensure smooth plant operation with timely signalling of alarms. The systems are also geared to provide vital data at shop floor level right through to vertically structured systems which encompass supervisory control and data acquisition (SCADA), manufacturing execution systems (MES) and interfacing with complex enterprise resource planning systems (ERP), which may be connected across multiple production sites.

11.4.1 Programmable Logic Controller

The programmable logic controller (PLC) is the most common choice in modern control [11]. It is a microprocessor-based system which can communicate with other process control components through data links. PLCs commonly use the so called *ladder logic* which was originally developed for electrical controls using relay switches. Programs can be written using a variety of languages. Once the program sequence has been entered into the PLC, the keyboard may be locked or removed altogether for security. When a process is controlled by a PLC, it uses inputs from sensors to take decisions and update outputs to drive actuators, as shown in Fig. 11.6.

Thus, a control loop is a continuous cycle of the PLC reading inputs, solving the ladder logic and then changing the outputs. A real process will inevitably change over time and the actuators will drive the system to new states (or modes of operation). This implies that the control performance relies on the sensors available and its performance is limited by their accuracy.

11.4.2 Supervisory Control and Data Acquisition

The supervisory control and data acquisition (SCADA) system is not a full control system, but is a software package that is positioned at a supervisory level on

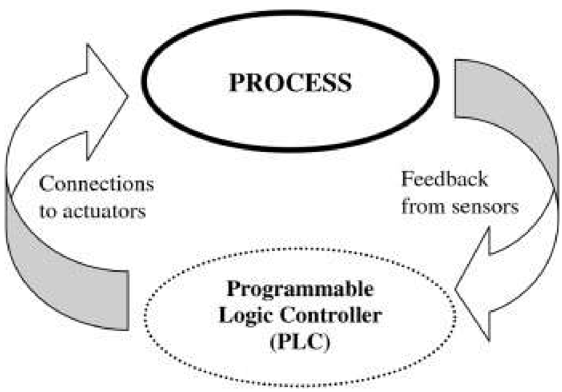

Fig. 11.6 Schematic illustration of the working of a programmable logic controller (PLC).

top of hardware to which it is interfaced, generally via PLCs, or other hardware modules [12]. SCADA systems are designed to run on common operating systems. Two basic layers can be distinguished in a SCADA system: (1) the *client layer* which serves as the human-machine interface and (2) the *data server layer* which handles process data and control activities, by communicating with devices such as PLCs and other data servers. Such communication may be established by using common computing networks. Modern data servers and client stations often run on Windows NT or Linux platforms. SCADA-based control systems also lend themselves to being scalable by adding more process variables, more specialised servers, e.g. for alarm handling, or more clients. This is normally done by providing multiple data servers connected to multiple controllers. Each data server has its own configuration database and realtime database (RTDB) and is responsible for handling a section of the process variables, e.g. data acquisition, alarm handling or archiving. Reports can also be produced when needed, or be automatically generated, printed and archived. SCADA systems are generally reliable and robust and, more often than not, technical support and maintenance are provided by the vendor.

11.4.3 Manufacturing Execution Systems

Manufacturing execution systems (MES) [13] are software packages which have been used for a number of years in process industries to support key operations and management functions ranging from data acquisition to maintenance management, quality control and performance analysis. However, it is only in recent years that there has been a concerted attempt to integrate factory floor information with *enterprise resource planning systems* (ERP). Modern MES include supply chain management, combine it with information from the factory floor and deliver results to plant managers in real time, thus integrating supply chain and production systems with the rest of the enterprise. This gives a holistic view of the business that is needed to support a 'manufacture to order' model. MES can manage production orders and can track material use and material status information. The software collects data and puts it into context, so that the data can be used for both realtime decision making and performance measurement and for historical analysis.

A typical control system currently available for dairy plants is shown in Fig. 11.7 [14].

The system combines supervision and control into a single concept, but its architecture is essentially open and modular, thereby delivering the operational flexibility needed. *Operator control* is the link between the plant operator and the process control modules, which enables actions such as routing and storage tank selection to be initiated at the click of a mouse. Using a variety of software tools, it is possible to incorporate a graphical presentation of the plant and other written information. Using the zoom facility, an operator can quickly access more detail on any given section of the plant. This feature can also be used to

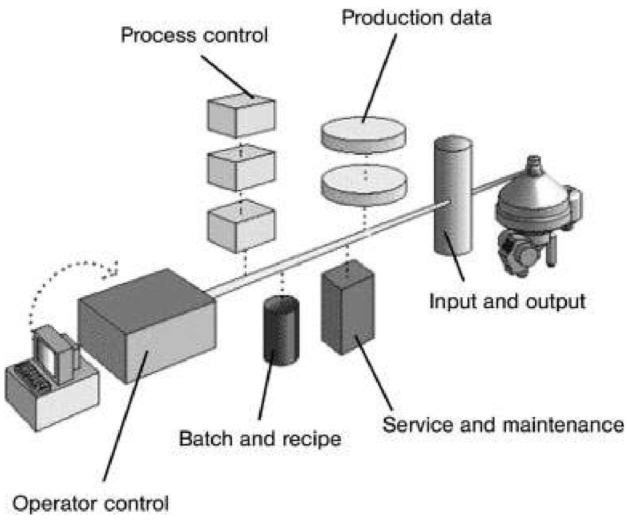

Fig. 11.7 A typical control system for dairy plant: FOOCOS system from ABB Automation [14]; reproduced with permission.

train new operators. Process data are also stored in this section, which can be easily accessed, for instance via 'pop up' control windows. The *process control* model contains information on the process and the parameters which have to be controlled. It can also include flow routing and control, storage information and sequences of the cleaning cycles. These modules can provide realtime control capability. The *batch and recipe* section contain information on recipe, ingredients and product specifications. This ensures use of ingredients in the right proportion and consistent product quality. All critical parameters can be monitored in realtime graphs and displayed on screen as well as logged for reports. The *production data* modules form a logbook of the activities of each processing unit – giving the origin of the product, how it has been treated and its final destination. The logbook can also be used for process evaluation and establishing traceability. The *service and maintenance* modules log information on equipment run times, number of valve strokes, alarm limits on equipment, etc., which identify poor functioning or worn units, well ahead of a possible breakdown. This enables the implementation of a preventative maintenance programme. Finally, the *input and output modules* handle the actual connections from the process control and supervision to the physical parts (like valves, pumps, etc.) to give a complete and detailed inventory.

11.5 Concluding Remarks

Most food businesses are currently facing constraints on capital budgets. There is a perpetual need for improving efficiency and seeking out valuable incremental improvements in manufacture. Proper implementation of process control is one way to release latent potential in existing processing facilities. Savings to be made by various sectors of the food and drink industry by implementing appropriate control of the manufacturing process are given in 'Energy Wizard', which is an interactive energy efficiency guide aiming to provide companies with free, independent and authoritative advice on many aspects of efficient energy use [15].

References

1 McFarlane, I. **1995**, *Automatic Control of Food Manufacturing Process*, 2nd edn, Chapman & Hall, London.

2 Pyle, D. L., Zaror, C. A. **1997**, Process control, in *Chemical Engineering for the Food Industry*, ed. P. J. Fryer, D. L. Pyle, C. D. Rielly, Blackie Academic and Professional, London, pp 250–294.

3 Stanbury, P. F., Whitaker, A., Hall, S. J. **1995**, *Principles of Fermentation Technology*, 2nd edn, Elsevier, Oxford, pp 215–241.

4 Kress-Rogers, E., Brimelow, C. J. B. **2001**, *Instrumentation and Sensors for the Food Industry*, 2nd edn, Woodhead, Cambridge.

5 Moreira, R. G. **2001**, *Automatic Control for Food Processing Systems*, Aspen, New-York.

6 Cooper, D. **2002**, *Practical Process Control using Control Station*, Course Notes, Control Station. www.controlstation.com.

7 Wellstead, P. E., Zarrop, M. B. **1995**, *Self-Tuning Systems: Control and Signal Processing*, John Wiley & Sons, Chichester.

8 Albertos, P., Antonio, S. **2004**, *Multivariable Control Systems: an Engineering Approach*, Springer, New York.

9 Zhang, Q., Litchfield, J. B. **1991**, Fuzzy mathematics for product development, *Food Technol.* 45, 108–115.

10 Eerikainen, T., Linko, P., Linko, S., Siimes, T., Zhu Y.-H. **1993**, Fuzzy logic and neural network applications in food science and technology, *Trends Food Sci. Technol.* 4, 237–242.

11 http://claymore.engineer.gvsu.edu/~jackh/books/plcs/chapters/plc_intro.pdf, accessed 3 July 2005.

12 Daneels, A., Salter, W. **1999**, Selection and evaluation of commercial SCADA systems for the controls of the CERN LHC experiments, *Proc. Int. Conf. Accelerator Large Exp. Phys. Control Syst.*, p. 353, available at: http://ref.web.cern.ch/ref/CERN/CNL/2000/003/scada/.

13 Fraser, J. **2003**, MES as enterprise application, not just plant system, available at: http://www.entegreat.com/eg_news_msifraser_20031110.htm.

14 http://www.abb.com/global/abbzh/abbzh251, accessed 3 July 2005.

15 http://www.actionenergy.org.uk, accessed 3 July 2005.