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The Market for Diagnostic Devices in the Food Industry

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18.1 Introduction

The food industry is, in general, driven by consumer demands and by governmental legislation. The impact of (social) media and NGOs is, nowadays, of high importance towards public perception. Therefore, consumers are increasingly aware of food safety issues and the effect of food on well-being. They are demanding higher-quality, fresher products, with fewer additives. Aspects like vegan, ethics and animal welfare are the focus of many consumer discussions. Moreover, it is known now that a large part of the population is allergic to some foods. In rare cases, allergens may have severe – even life-threatening – consequences. Consumers, therefore, need to know what is in the food they buy – hence, regulations in many countries require that manufacturers declare the presence of potential allergens on the label. This puts severe pressure on the industry, because it needs to comply with accurate labelling and stringent tracking and tracing systems to be able to respond instantly to any (real, potential, or perceived) incident.

On top of these requirements, the food industry is faced with the complexity of today's supply chains. Ingredients are sourced from all over the world (globalisation), spreading food-related hazards as fast as the ingredients and products move. Consequently, surveillance must be stepped up to be able to keep hazards due to micro-organisms, allergens (labelling), and chemical and physical contamination under control. From an economic point of view, food production has to face market increasing price volatilisation for primary agro products, while prices in the supermarkets remain stable. Furthermore, growing competitiveness has to face global quality standards, as well as environmental concerns, and more stringent regulations will boost the demand for analytical instrumentation (Frost and Sullivan, 2014). Some of the requirements both parties (consumers and legislation) put onto food manufacturers are listed in Table 18.1.

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Table 18.1 Quality and safety requirements put onto the food industry.

Consumer demands
Absence of chemical residues (e.g. pesticides, veterinary drugs, cleaning agents)
Absence of chemical contaminants (e.g. heavy metals, persistent organic pollutants like dioxins, polyaromatic hydrocarbons) Absence of non-declared allergens (e.g. traces of peanuts)
Absence of foreign bodies (metal, glass, plastic, insects or parts thereof)
Correct labelling, including nutritional data
Microbial stability as well as absence of pathogens
High quality, culinary experience
Long shelf life, without noticeable quality loss or sensorial impact
Acceptable cost
Aspects like animal welfare, regional production, GMO-free products

18.2 Food diagnostics

The consequence of all this is that the food industry needs to know more about the product than ever before. Traditionally, food processors would like to be able to control the process. However, to measure process parameters at the place of production and to obtain maximum certainty with respect to regulatory requirements and consumer demands, many more diagnostic devices are needed or highly desirable. At the place of production, it means that these devices – in contrast to external commercial analysis – work at least at-line or by-line, and better on-line or in-line during food production. There is a market for devices that:

- measure in a given range (e.g. EU regulations – based on Reg (EG) No 178/2002) everything that helps to comply with the preceding requirements;
- can be implemented in an existing quality assurance system and also with respect to data management;
- work accurately, reliably, and are long-lived;
- have a sufficiently short response time;
- are hygienic (do not adversely affect the runtime of the process line or the quality of the product);
- are easy to operate, maintain, dismantle, and reassemble; and
- are affordable for the food industry.

In the following paragraphs, examples of what would be used by the industry if available, and complying with these requirements, are provided.

18.3 Product composition

It is important to be able to detect any undesirable substances in the raw materials and intermediate and final products (Table 18.2).

Table 18.2 Undesired substances in raw materials and intermediate and final products.

Threats	Primary production	Processing	Logistics	Retail

Biological:
• Bacteria
• Virus
• Yeast
• Fungi
	• Identification and quantification by plate count agar, PCR	• Identification by plate count agar, PCR
		• Treatment by:
		  • Heat
		  • Blanching
		  • Spray nozzles (sanitation)
		  • Ozone generation for sanitation systems
			• Intelligent packing
			• Transport temperature control
			• Antimicrobial packing
			• Self- cooling/ self- heating packages
			• Atmosphere control
				• Radio-frequency identification (RFID)
				• Time temperature indicator (TTI)
				• Cooling storage
				• Temperature control
				• Intelligent shelves
				• Information via smartphone
				• Combined with customer service

Chemical: • Pesticide • Veterinary drug • Contaminant (e.g. heavy metals) • Cleaning agents	• Identification and quantification by reference analysis like chromatographic and spectroscopic methods – conducted by external commercial labs or in-house QA in a chemical lab	• Identification and quantification by reference analysis like chromatographic and spectroscopic methods – conducted by external commercial labs or in-house QA in a chemical lab	• Control not mandatory and therefore, in principle, not conducted	• Information via smartphone combined with customer service • In the case of 'own brands': QA by external labs – controlling the standard parameters (see left)
Physical: • Bones • Metal • Wood • Plastics • Glass	• Human inspection • Raw material inspection and specification • Metal detectors, X-ray technology • Magnetic traps • Electronic bottle inspection (for empty glass) • Bone separator	• Human inspection • Raw material inspection and specification • Metal detectors, X-ray technology • Magnetic traps • Electronic bottle inspection (for empty glass) • Bone separator	• Appropriate handling of packaging material, proper shipping	• Information via smartphone • Combined with customer service

18.3.1 Physical hazards

Any extraneous object or foreign matter in a food item that may cause illness or injury to a person consuming the product. Sources for such contaminants include raw materials, badly maintained facilities and equipment, improper production procedures and poor employee practices.

Foreign bodies have been the cause of incidents many times. Metal detection – in contrast to plastics and bones – is relatively easy, although calibration and sensitivity are still causing problems. For other foreign bodies, there are no generally applicable and reliable detection devices. Some progress has been made with optical methods to detect foreign bodies present in empty glass jars and bottles. However, most manufacturers still rely on prevention and the use of sieves/strainers to capture and remove foreign bodies. Detection devices are preferably placed close to the filling machine, to minimise the chances of contamination. For aseptic ultra-high temperature (UHT) treatment lines, this often means that the device has to be resistant to sterilisation by steam or water of over 120°C and 3–5 bars of pressure. This can be a problem for in-line metal detectors, as these often have fibre-reinforced plastic housing to allow transmission of the sensor waves.

18.3.2 Biological hazards

Food products should not contain undesirable microorganisms in concentrations that may cause harm to the product and consumer. Being able to know the concentration of microorganisms at any time will provide the information needed to decide when a process needs to be stopped for cleaning and sanitation of the processing equipment. Therefore, devices that are able to detect microbes by smelling (electronic noses) are of great interest for the food industry, but are not yet commercially available. It is also important to be able to distinguish between pathogenic/toxigenic and spoilage microorganisms. Combining immunological principles and electronic devices with a high sensitivity for changes in their direct environment has led to some very specific sensors for particular pathogenic microorganisms. It may be expected that combination with nanotechnology will provide very advanced sensors that will enable food processors to detect the presence of harmful microbes, even before a product is packed. For such sensors, the market will be huge, as it will greatly help to prevent food-borne safety incidents. Self-evidently, they need to be developed into robust industrial devices.

18.3.3 Chemical hazards

These occur when chemicals are present in foods at levels that can be hazardous to humans. Some potential chemical hazards could occur prior to a processor receiving product, such as the improper use of pesticides, antimicrobial and veterinary drug residues, or toxins (mycotoxins, natural toxins, and marine toxins). Others could be chemicals used on processing equipment, such as oils used on equipment or sanitisers.

18.3.3.1 Metals

Raw materials may be transported in metal containers, and may be stored in stainless steel tanks, and processing, in most cases, takes place in stainless steel machinery. Stainless steel consists of a variety of metals, including iron, chromium, nickel, and molybdenum. Processing equipment with moving parts is likely to have components

made from other materials, such as bronze (often used for bearings). Depending on product and processing conditions, there may be chemical and electrochemical reactions, as well as mechanical wear.

Most food products contain sodium chloride and water, and that results in chemistry, even with most, if not all, qualities of stainless steel. If the food is acidic and processing is at elevated temperatures, the reaction rates may be quite high. If materials in the same equipment in a process line differ, there will be electrochemistry. This all may result in an increase in the metal concentration of the product. In principle, this need not be alarming, as the human body actually needs the metals. The concentration, however, should never be so high as to have a significant influence on the healthy daily uptake. Another reason for watching metal concentrations is that they provide information on wear of the equipment, and the need for maintenance (e.g. lubrication) or replacement.

18.3.3.2 Pesticides

Although much effort is placed on avoiding the use of pesticides, in the vast majority of agricultural areas, their use is unavoidable for the production of the amount of food needed. Where cultivars are selected that are more resistant to pests and, hence, may need no or less pesticides ('organic farming'), there is a chance that the variety contains high 'natural' concentrations of pesticides, which may be counterproductive from a food safety point of view. Concentrations of pesticides, if properly used, should be present only in very low, harmless concentrations. They may be high, however, as a result of carelessness. Nevertheless, nothing is known of metabolites generated during food production. Simple and affordable methods for detecting pesticides and their metabolites will no doubt find a market in the food industry.

18.3.3.3 Organic contaminants

Besides persistent organic pollutants (e.g. dioxins, polyaromatic hydrocarbons), microbial toxins are undesirable and should not exceed acceptable concentrations. Because of the nature of the world, there will always be microorganisms that grow where food is harvested; without them, there would not be any soil to grow our food. A consequence is that toxins – and, particularly, mycotoxins – are abundant, and measures should be in place to source food and ingredients with harmless concentrations. Because it is not realistic to transport and store raw materials aseptically, moulds will always be present. Giving them the chance to grow may result in an increase in the concentration of such toxins.

Microbial growth may be restricted by control of relative humidity (RH) and temperature. At RH < 60 %, most moulds are unable to grow. Cooling to reduce the growth rate of microorganisms may be useful, provided that care is taken to prevent significant differences in temperature between parts in the bulk of raw materials. Moisture will migrate to cold spots, and increase the water activity locally to 1 (equivalent to RH of 100 %). Measurement of RH and temperature is, thus, important but, in addition, direct measurement of the concentration of toxins, providing proof that the susceptible product is safe or unsafe, is highly desirable.

18.3.3.4 Allergens

The number of people suffering from food allergenicities is increasing. Even the apple that should 'keep the doctor away' may be unhealthy for many. Most allergens are

proteins, and their selective detection in an environment of a mixture of other proteins is based on antibody technology, and is quite complex. In some cases, detection of indicator molecules may be more rewarding, such as lactose being an indicator of the (likely) presence of milk and, thus, milk's proteins. It would, of course, not help if lactose-free milk products have been used on a process line that is subsequently used for 'milk-free' products. There is obviously scope for devices that instantly can detect proteins selectively, and devices that are able to measure other metabolites, indicative for allergens, instantly. Up to now, it seems – due to the fact that there is no specific threshold for allergens – it is quite challenging to find an analytical solution.

18.3.4 Metabolites

A) Resulting from enzymatic or microbial activity, these can be used to determine the freshness of a product. This could be used at the level of the consumer, or upstream in the supply, during selection of ingredients. At the consumer level, it could, for example, allow the consumer to follow the ripening of fruits and signal the optimal moment of consumption. In other products, it might be as simple as indicating a pH change caused by the presence of lactobacilli. During manufacturing, it could be used for the selection of ingredients – for example, to measure the ripeness of batches of fruits and vegetables in a non-intrusive way. Only batches at optimum ripeness would be used in processing. In many processes, enzymatic and microbial activities are essential. Examples are the fermentation of tea, yoghurt, cheese, and sauerkraut. Many times, very basic measurements are done to control the process. The fermentation of tea is controlled by watching the development of the colour during fermentation. The final test takes place after the tea has been dried, by a taste expert. Obviously, this is relatively late. Ideally, measurement should be done in-line, be directly related to the desired property, and be suitable for direct process control. Some gas sensor arrays, also called electronic noses, are already capable of detecting volatile compounds – major impact compounds, as well as off-flavours. The major challenge will be to implement them into a production surrounding.
B) **Process metabolites**: since 2002, when acrylamide was identified in many heating processes, this kind of contamination has been receiving more and more attention. The change of technologies fostered by resource efficiency approaches will generate new threats. Beside this, the impact of primary and secondary metabolites of plant protection chemicals is still unclear.

18.3.5 Desired product constituent*s*

As consumers increasingly realise the importance and the effect of food on well-being, more and more products will target their concerns. Ingredients include the well-known vitamins and minerals, but currently unknown ingredients will probably be discovered. It is, however, also useful to know the actual concentration of desired, valuable substances, such as those listed in Table 18.3.

18.3.6 Source of constituents

In the near future, an array of new ingredients contributing to the health benefits of foods is expected to emerge. The quest for new heath-stimulating ingredients has only

Table 18.3 Desired product constituents and product structure.

Product constituents
Proteins
Individual amino acids
Sugars
Healthy fatty acids as well as the total concentration of fatty acids
Compounds with an additional health impact, e.g. antioxidants
Vitamins, especially those that address a population's deficiencies
Flavour and taste compounds

just begun. Instead of synthesising these ingredients in a chemical way, much is expected from extraction of plant material. When the plant material has a history of consumption, this will facilitate clearance of the ingredients for use in foods significantly. Plant material is known for its variation (depending on the season, soil, fertilisers, etc.). When ingredients are prepared from fluctuating sources, measurement (and control) is key to ensuring the right level of active ingredients.

18.4 Product structure

To be acceptable, product structure needs to comply with consumer expectations. Therefore, it is important to ensure that the structure-determining parameters in Table 18.5 are within limits.

18.4.1 Viscosity

There are many measurements to quantify the texture of food. Some are based on physical principles like viscosity, while other methods are developed to mimic a consumer-desired attribute – for example, the ability of ketchup to flow from a bottle onto food. As pourability is difficult to relate to a simple viscosity measurement, companies have developed their own practical ways to measure this property. In the case of ketchup, this can be done by placing a small reservoir of product on a defined slope. After removing the container, the ketchup will flow downward from the slope. The length of the trail can be used to indicate the pourability of the product. Sensors that could measure viscosity in-line would be ideal.

The most straightforward solution to measure its properties in-line would be measuring the pressure loss of the product when it flows through a pipe. This is difficult to accomplish, and further complicated by the fact that many products do change texture during storage.

18.4.2 Air/gas

For some products, like ice cream, the amount of air per volume of product is an important parameter, as it has a major influence on the product texture (and also on the cost of

the product per volume). In-line measurement of aeration is desirable, but is complicated by pressure fluctuations in the process line, leading to fluctuating gas/liquid volume ratios. Also, when the product is in the supply chain, monitoring the air content (or crystal size) is useful to check for any temperature abuse.

In other products, the presence of air is undesirable, and a lot of effort is paid to de-aeration and gentle filling. Sensors that could check for the presence of air/gas in a non-intrusive way could find application.

18.4.3 Crystal size

Ice cream is probably the product influenced most by crystal size, although fat crystals play a role in other foods. Better measurement during production would make it possible to deliver a more constant quality to the consumer. Probably more important are the changes during distribution that could severely degrade the quality. Predicting the crystal size only by temperature history is difficult or impossible. A simple, non-intrusive crystal size sensor could be used when the product is placed in the freezer, or when bought by consumers.

18.5 Influence of processing on product composition

Processing may result in the formation of desirable and undesirable substances, or these may be the result of contamination during processing (Table 18.4).

18.5.1 Reactions between naturally present substances in food

Much food requires heating to become palatable, and to make the nutrients that the human body needs available. Heating, however, may have undesirable side-effects, such as some of the Maillard reaction products (e.g. acrylamide). Often, the production of such substances can be controlled by careful selection of cooking (or, in this case, frying) conditions. In many vegetables, nitrates are converted to nitrites and, in the presence of proteins, into nitrosamines. Both may be carcinogenic in high concentrations and, therefore, their formation should be prevented.

In products with both ascorbic acid and benzoate then, with time, benzene will be formed, even at ambient temperature. Food products are, by nature, very complex, and a vast number of chemical reactions, some known and many unknown, will take place during processing. With time, more of these reactions will become known, and there will be an ever-increasing demand for methods of analysis and, hence, diagnostic devices that can be used industrially.

Table 18.4 Substances resulting from food processing.

Maillard products
Nitrite
Nitrosamines
Polycyclic aromatic hydrocarbons (PAHs)
Cleaning and disinfection agents

18.5.2 Contamination with cleaning and disinfection agents

Although contamination with chemicals during processing ought to be avoided by the correct design of the process line and skilful operation by trained operators (Lelieveld *et al.*, 2016), incidents may occur (e.g. failure of seals) that can only be noticed through measurement, and not by observation. Therefore, measurement of such contamination is highly desirable. Contamination of a product by cleaning-in-place (CIP) fluids could be measured by an in-line pH (or equivalent) measurement just before the filling machine.

18.6 Processing parameters

Processing is done to convert raw materials into desired products that are safe. Obviously, accurate control of the processing parameters and, hence, the capability of measuring these parameters, are essential. To inactivate microorganisms and to arrest or reduce enzymatic activity (e.g. blanching), heat treatments are traditionally applied. Novel processing methods, also with respect to resource efficiency, have been introduced that are based on other physiological effects than that of heat, such as (very) high pressures or (pulsed) electric fields. Also, methods have been developed that still use heat, but reduce the total heat input by (for example) faster heating (ohmic and microwave). Such methods require control of other parameters, such as pressure, field strength and flow distribution. Process parameters that may need control and, hence, diagnostic devices, are listed in Table 18.5.

Table 18.5 Process parameters to be controlled.

General
Temperature and temperature distribution
Flow rate and velocity profile/distribution
pH, pO_2
Humidity
Pressure
Colour
Turbidity
Viscosity
Structure
Droplet, bubble, crystal size and distribution
Fouling of product contact surfaces
Additional parameters for high-pressure processing
Pressure (up to 1000 MPa)
Temperature distribution in the high-pressure vessel
Pressurizing rate

18.6.1 General

Most of the parameters listed under 'general' in Table 18.5 need no further explanation. Their importance was established long ago, and measurement of most of them is possible, although there is scope for improvement, in particular with respect to hygienic design. Many temperature and pH probes used in the food industry are of a design that results in products accumulating in dead zones that are difficult to clean and where, during processing, microorganisms multiply and contaminate the passing product (Lelieveld *et al.*, 2014). The availability of hygienic devices is limited, and there is scope for affordable designs that do not affect the flow pattern of the product.

18.6.2 Flow rate and velocity distribution/temperature and temperature distribution

All thermal preservation processes are determined by exposure of the product to a heating process for a certain time. Long heating times will reduce the quality of the product. The trend is to reduce the heat treatment as much as possible, by making it fast and homogeneous. The heating process can be conventional, based on conduction and convection, or advanced and based on induction of heat by an electric field (ohmic, radio-frequency, microwave heating). The intensity of the heat input, coupled with the residence time, determines the final temperature of the product.

For conventional heating of a product flowing through a straight pipe and heated from the outside, the coldest product will be found in the centre, which would be the appropriate place for mounting a thermocouple, to monitor and control the temperature. To increase the homogeneity of the temperature, mixing perpendicular to the flow is used (e.g. by bending the pipe and inducing secondary flows or by application of static mixers). Now, however, the position of the coldest particle is unknown and, ideally, the cross-section should be scanned to identify the coldest particle. After heating, the product is held at an elevated temperature to obtain the desired inactivation. The minimum heat treatment is given to the particle with the shortest residence time.

The preceding process is complicated by the presence of particles in the fluid. This is because heat penetrates only slowly into the particles, and particles have a velocity different from that of the fluid and are not homogeneously distributed over the cross-section. To determine the effectiveness of a heating process, experiments are done by sending small, floating temperature loggers through the process – or, indirectly, by sending particles filled with a known chemical species through the line, and deriving the heat treatment from the chemical conversion. Although this provides much insight, it should be realised that the aim of the preservation step is a reduction of microorganisms by a factor of 106–1012, implying that the tiniest particle that does not receive the right heat treatment may cause problems. To determine an accurate description of the process, high numbers of sensors should be sent through the process.

To minimise the thermal damage, temperatures are raised and holding times are shortened. In the extreme case heating is done by steam injection, and the holding time reduced to less than a second. Determining velocity and temperature distributions in such a case is still a challenge.

18.6.3 Droplet, bubble, crystal size and distribution

Apart from the influence on viscosity and mouth-feel, for water-in-oil emulsions, water distribution often plays an important role in preservation. If the droplet size is small, bacteria are trapped in a small amount of aqueous solution containing limited nutrients. Consequently, growth is nutrient-limited, and spreading of the bacteria is prevented – unless, of course, it has sufficient lipase activity. In combination with other hurdles for microbial growth, like a sufficiently low pH, margarine is often preserved this way, reducing or eliminating the use of preservatives.

18.6.4 Additional parameters for high-pressure processing

High-pressure processes that are currently applied are done at room temperature, with the aim of inactivation of vegetative microorganisms. The inactivation is mainly based on pressure, and hardly on temperature. For control purposes only, the pressure needs to be measured which, in the case of liquid product, is homogeneously distributed throughout the vessel, therefore allowing a single measurement position. Although pressures are high (typically 500–700 MPa), reliable sensors exist. When the product is not a liquid but a solid, such as meat/bone, it would be interesting to measure the pressure inside a piece of meat/bone.

More recently, the use of high pressure for sterilisation has been shown to be reliable, in combination with heat (Bermúdes-Aguirre *et al*., 2016). Here, inactivation of microbial spores is the aim, and temperature plays a key role. The process is based on the use of adiabatic heating of the product. Under pressurisation, the product will rise in temperature, which is essential for the inactivation of microorganisms. Most products will rise 3–5°C per 100 MPa. Starting temperature is typically around 90°C, and the target end temperature is 110–120°C. The wall of the vessel will not rise in temperature during compression, and will act as a heat sink. Immediately after compression, products close to the vessel wall will drop in temperature and, therefore, fail to sterilise. In the case of sterilisation, the measurement of the temperature in high-pressure vessels is essential. Drilling holes in the cover of the vessel for mounting temperature probes is not feasible from a mechanical point of view. There is a clear need for a temperature-logging device that would resist 120°C and 700 MPa.

18.6.5 Pulsed electric field (PEF) processing

After 60 years of research and development, this novel technology has found industrial applications. Contrary to thermal preservation methods, PEF has no effect on flavour and nutrients and, hence, PEF treated products cannot be distinguished organoleptically from fresh products. This is of particular interest for fruit juices; PEF treated juices cannot be distinguished from freshly squeezed juices, so the technology is used for the extension of the shelf life of fruit juices. The first company making PEF-treated fruit juices was Genesis Juice Cooperative in Oregon, USA, who put a range of PEF-treated fruit juices on the market in 2005. The company was taken over a few years later, and the PEF process was replaced by a high-pressure process.

In the Netherlands, however, research and development continued, which resulted, in 2011, in a Dutch company starting to apply PEF on a large scale to enhance the shelf life of

fruit juices (Smit, 2012). Today, the products are on the market in the Netherlands and many other European countries. In 2010, a Dutch company started to develop equipment for cooking using PEF. It appeared to be possible to cook meat, fish, potatoes and vegetables in an extremely short time (seconds rather than minutes), and to obtain a quality that is appreciated by top cooks and others, to the extent that the company has received several prizes/awards. The technology is nicely described in 'e-Cooking' (IXL Netherlands, 2016).

The effect of PEF is based on the detrimental influence of electric fields on the membrane surrounding the cells of both microbes and higher organisms. Microbial membranes consist of a double layer of phospholipids that are polarised and neatly arranged, to separate the contents of the microbial cell from the environment. To allow the access of selected nutrients and excretion of metabolites, dedicated 'pumps', consisting of special proteins, are needed. Electrical fields, in the order of 1 volt per micrometre, affect the integrity of the phospholipid membrane, causing it to leak and 'bleed to death'. The effect is achieved by using pulses with a duration of a few microseconds. If the electrical field strength is insufficient, or the time is too short, the cell is able to repair the damage. On the other hand, if the field strength is too high and the duration too long, too much energy will be put into the product, raising the temperature to values that cause thermal damage the product, as with traditional thermal pasteurisation.

Another effect of PEF is that it destroys the connections between cells of both plant and animal products, making the product softer (vegetables) or tender (meat). Heat has the same effect and, for many foods until now, heating has been the only way to make them palatable, be it by conventional methods (boiling, steaming) or by using newer techniques (microwave, radio-frequency, ohmic). Meat is difficult to digest without cooking, and some meat (e.g. stewing meat) needs hours of thermal cooking to become tender enough for consumption. With PEF, this process takes less than a second. There are other – meanwhile also industrial – applications of PEF that require sensors to allow process control.

For a PEF treatment to be effective, it is essential that all cells, whether microbes or cells of higher organisms (vegetables, meat) receive the correct treatment – that is, the required number of pulses, of the correct shape and duration, and at the required field strength – so that, for microbes, the damage to the cell is irreversible, and for the foods, all parts of it are palatable. Consequently, for treatment of liquids, the residence time distribution and, thus, the flow pattern, are important.

For both liquid and solid foods, the degree of homogeneity of the field strength is important. Because the field strength is affected by differences in conductivity which, in turn, is influenced by differences in temperature, it would be of great interest to be able to measure the temperature in the product without disturbing the electric field, and without heating the probe more than the product surrounding it. Ideally, there should be sensors that could be suspended in a product to facilitate the adjustment of the correct (i.e. energetically most economical) process conditions.

18.7 Packaging parameters

Quantities of product sold must be measured, which is why we have weighing scales and volume measurements. In-line weight measuring and control are widely used, and are flow meters that dispense measured quantities of liquid or fluid solids into containers. For aseptic packing, there are additional parameters to control:

- air flow, to certify that air is going out of the sterile zone and not into it;
- air quality, to ensure that the air entering the sterile zone is sterile;
- concentration and temperature of the sterilising agent, often hydrogen peroxide; and
- container seal integrity.

18.7.1 Sterility testing

To have at least some assurance that an aseptically packed product is safe and free from relevant microorganisms, packs are sampled for analysis. Sample containers opened for analysis, however, are wasted, and present a significant loss of product, as well as an environmental burden. Moreover, unless 100% is sampled and, thus, nothing is left for sale, sampling provides only a *chance* that all packs are sterile and, thus, are indeed safe. Non-destructive methods would, therefore, offer great savings.

In the dairy industry, non-destructive testing has been applied for several decades: a device called Elektester measures energy absorbed by mechanically vibrated packs. Deviations in the energy absorbed means that the viscosity of the product in the pack is different and, thus, something must be wrong with its contents. The method has limited application, as many products do not change in viscosity as a result of microbial activity. There are, however, other parameters that do change as a result of microbial activity, such as electrical impedance, which can also be measured in a non-invasive way (Nihtianov and Meijer, 1997). Regrettably, at this time, this method is not yet commercially available. A third method, using similar electronics, measures volume changes (Nihtianov *et al*., 2001). The growth of microorganisms may result in the production of gases or change the density of the product, resulting in changes in volume that, even if very minor, can easily be measured accurately. Finally, the temperature rise caused by microbial activity can be measured, using so-called 'smart sensors' that allow reliable detection of mK differences in temperature.

The combination of a series of non-destructive methods would cover a large range of microorganisms, and make sterility testing of products efficient. It would allow a larger sampling rate at affordable costs, due to the savings resulting from elimination of labour- intensive, destructive testing, avoiding product loss and reduction in waste.

18.8 Conclusion

It is clear from this chapter that the *potential* market for food diagnostics is huge. Analysing complex food samples will be a challenge, as well impact Industry 4.0. Countries such as China, India, and Brazil are acting as production hubs for food manufacturing and as sources for raw materials (Frost and Sullivan, 2015). The majority of parameters that the industry would like to measure cannot be measured in an industrial way. This is a task for research, development, and particularly industrialisation of diagnostic possibilities that have been developed, but of which application remains restricted to laboratories. The possibilities that micro- and nanotechnology offer will, hopefully, stimulate the availability of the diagnostic tools that the industry needs.

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