What food processors should know: metal detection or X-ray inspection

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Keeping pace with a shift in regulatory focus

Consumer safety has always been a primary concern for food processors. HACCP (Hazard Analysis and Critical Control Point) has been a methology recommended by the FDA since the 1950s and food producers have always been conscious of their brand's protection. The enactment of the U.S. Food Safety Modernization Act (FSMA) turned the intensity up even higher.

With significant food safety costs and penalties, processors will be relying more than ever before on the latest quality control methodologies and equipment to keep the food supply safe.

Although recalls due to Listeria, E. coli and Salmonella may be grabbing headlines, foreign object contamination is an equally important food safety issue—and a very common occurrence.

Most raw foods and ingredients originate in a natural environment—a field, an orchard, a farm, etc. As the food is picked or harvested, foreign objects such as stones or glass can end up comingled and transported into the processing plant. Additionally, metal and plastic components of processing and handling systems can find their way into the product stream. Lastly, fragments of bones and other unwanted materials, that are not successfully removed during processing, can end up hidden in final products.

In addition to more stringent regulations, retailers have also started to make product inspection demands on food processors—even refusing to do business with those not employing the latest technologies.

With these drivers currently in place, the objective of this white paper is to review the attributes of both metal detectors and X-ray systems and when each may be best suited. The technologies are frequently deployed at different points in the production process which means it is not uncommon to find both on the same production line. The goal is to provide food quality professionals with comparative information which can then be used to make the right decision for individual product and processing requirements.

The challenge

Metal detection and X-ray inspection have traditionally been the first line of defense to detect the presence of foreign object contaminants in food products before they have the chance to leave the processing plant.

For food quality professionals, process engineers and corporate food safety executives who must decide which technology will best protect them from contaminants, choosing a detection system is typically based on three things: the optimum inspection point, overall application capability and total cost/benefit.

However, even though detection technologies have been employed by food processors for decades, engineering and software improvements continue to set new standards. This has led to some confusion regarding which technology to employ and why.

The basics

In security applications, such as airport screening, metal detectors use radio frequency signals to react to moving metal e.g., coins in your pocket. X-ray systems produce density images that are analyzed for irregularities.

Deploying these technologies for food applications is more complex. The size and type of anomaly being detected is more challenging (i.e., smaller and sometimes hidden in the product) and the rapid speed in which the detection needs to take place makes the process more complex. In fact, in many cases, the real challenge isn't finding the contaminant; it is ignoring the product, packaging or environment. False detections add up to big costs and high frustrations, too, so the detections must be extremely reliable.

Metal detectors and X-ray systems for food applications must be very sensitive, easy to use, have a high level of automation, fast, extremely robust, reliable, and cost effective. This is a tall order for any automated system that must run for many years in a hot, wet factory and make reliable pass/fail decisions on literally millions of products.

Foreign object detection performance is determined in three ways: detectable contaminant types, minimum contaminant size and probability of detection.

Below is a basic summary of detectable contaminant types by technology. Please note these are general guidelines. Situations can occur when contaminants can be missed, or conversely, foreign objects can be found that you thought didn't exist. The best practice prior to deployment is always to test many samples with different contaminants. This helps you understand how the product and contaminant react when in the detection system. See Table 1 below.

Minimum contaminant size depends on the system design/technology and the product effect (how much the food itself "looks like" a contaminant to the system). Probability of detection means "what is the chance of missing a contaminant in real production with real products running at real speeds?" Typically, the larger the contaminant the higher the probability of detection.

This fundamental trade-off is addressed by building in margin for error, setting periodic mandatory audits and performing preventative maintenance. Policies, procedures, training and discipline are the order of the day.

Selecting the detection point

Companies typically use the HACCP methodology to manage their food safety. The first part of the process (HA) identifies which contaminants are most likely to occur. Next is the determination of the (CCP)—or in the case of contaminants, the best detection point. CCPs can occur in multiple places: at the beginning of the process; after cutting, sifting or mixing; immediately after a bag or box is filled; or at the end of the line.

Detectable contaminant type	Metal detectors	X-ray systems	Comments
Ferrous metal	●●●	●●●	Ferrous, non-ferrous, and stainless steel different for MD, the same for XR
Non-ferrous metal e.g., brass or bronze	●●	●●●	
316 Stainless steel	●	●●●	
Aluminum	●●	●●	Density similar to glass, thin foil only detectable by MD
Wires	●●	●●	Depends on diameter, length, and orientation for both MD and XR
Glass		●●	Depends on density and size, ~ 3x less dense than stainless steel
Rock		●●	Depends on density and size
Bone		●	Depends on density and size, calcified bone only
Plastic		●	Depends on density and size, light plastics not reliably detectable
Wood, pits, shells, insects, etc.			Nonconductive for MD, not dense enough for XR

Table 1. Detectable contaminant types by technology.

Multi-sample test cards to evaluate X-ray performance

Ideally, the goal is to find problems early in the process to reduce the cost of rework or scrap while still ensuring the final product is safe. Inspecting large cases immediately prior to shipment is not always the right decision.

The optimum detection point can influence which technology should be employed. Metal detectors can be installed almost anywhere, but their performance depends on the size of the aperture (tunnel) the product passes through. In general, they work best for bulk conveyed or piped product or products in small packages.

X-ray systems are dependent on product size, too, but have greater sensitivity with large products than metal detectors. Due to the basic detector sensor scanning rate, X-ray systems are limited by speed. They are typically found closer to the end of the line but can be used as a first check for contamination too. X-ray systems equipped to handle bulk products like nuts can find glass or stone that metal detectors cannot. Because X-ray systems need a constant, known speed to construct images, they cannot be used in gravity flow applications. Metal detectors are ideal for these types of products.

Decision-making checklist

Before making a decision, answer this fundamental question: What contaminants do you want to find and where do they come from? See Table 2 below.

Given all the factors that affect application performance, the best way to select a technology and specific system is to run a test. Try everything to make the system fail. Strive for near 100% probability of detection with no false readings. Make sure you have enough detection margin so the system can run trouble free for hours without false rejects or the need for calibration.

X-ray inspection guidelines

X-ray systems create grayscale images in real time corresponding to the density and thickness of the inspected product. To detect a contaminant in those images the contaminant must have significant contrast compared to the product the contaminant is inside: the greater the density difference between contaminant and product, the greater the contrast difference between them in the image.

Metal detection	X-ray inspection
Detects metal including aluminum and wires.	Detects most metals and many other solid contaminants.
Can be used almost anywhere in a process; conveyors, drop-throughs and pipelines.	Best used for conveyor or bulk inspection.
Operates over a wide range of speeds.	Speed must be constant, and range. may be limited.
Conductive (wet/salty) products are the most challenging.	Dense products with lots of texture will be most difficult to achieve good performance.
Performance dependent on aperture size, product effect and software.	Performance dependent on X-ray power, receiver, product texture, and software.
Long life in even the harshest environments.	Moderate life in harsh environments, best in controlled environments.
Detects metals down to <1.0 mm in diameter.	Detects metals down to <1.0 mm in diameter, also finds dense nonmetallic contaminants down to <3.0 mm in diameter.
Dry products, small products, unpackaged products, or products with nonconductive packaging have best sensitivity.	Most packaged products have high sensitivity including metal cans, glass bottles and products packaged with metallized film or seals.
Highly flexible, cost effective detection solution suitable for multiple inspection points.	Effective detection and product verification for the widest range of contaminants and package types.

Table 2. Capability comparison between metal detection and X-ray inspection.

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Some typical contaminant material densities compared to water (i.e., water density = 1.0 g/mL)) and general X-ray system capability regarding the detection of these materials is shown in Table 3. As the contaminant becomes less dense the minimum detectable size increases. The only way to definitively determine what can and cannot be detected (material and contaminant size) is to have an application specialist run a test.

Baseline performance for metal detection sensitivity can be assessed by inspecting dry products that are not magnetic or conductive. Such testing indicates the smallest detectable sphere in the center of the aperture (worst case). Performance degrades for wet products, sometimes by up to 2x. Sensitivity may also decrease for products with a lot of variation. As real-world applications vary, the best way to fully assess performance is to perform testing using the actual product that will be inspected.

Detectable		Possibly detectable		Not detectable	
Iron	7.15	Nylon	1.15	Hair	0.32
Steel	7.86	PVC	1.38	Fruit	0.56
Stainless steel	7.93	Dense rubber	1.52	Insects	0.59
Teflon	2.19			Fish bones	0.60
Calcified bone	2.20			Wood	0.65
Stone	2.5 (avg.)			HDPE	0.92
Glass	2.50			UMHW	0.94
Aluminum	2.71			Ice	0.92

Table 3. Typical contaminant material densities compared to water.
Note: All densities in g/mL

Package material trends

The need to market products in packaging materials which cost-effectively enhance shelf life has led many brand owners to convert to metalized film or foil-based structures. These materials not only provide better oxygen, moisture and UV-light barriers, but they also improve shelf presence.

However, metal-based structures are not compatible with metal detectors. On the other hand, X-ray systems have no problem seeing right through these packages and are able to detect very small contaminants inside. In fact, X-ray systems can even be used to find glass contaminants inside glass bottles.

Packaging material trends will continue to be a critical factor in contamination detection choices.

Conclusion

X-ray inspection and metal detection systems are important parts of a complete food safety system. Both technologies have their value and can offer manufacturers and consumers important protection from potentially harmful foreign object contamination. When deciding on which technology or combination of technologies to use, food manufacturers should consider the risk factors and application specifics of their production. Product inspection equipment suppliers can help guide food manufacturers through this decision-making process, and fit the most appropriate technology to their particular needs.

Find out more at **thermofisher.com/productinspection**

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