Using foreign material detection methods to assist the food industry

by

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Abstract

Foreign material is a constant hazard of concern for the food and meat industries. Production facilities need to identify ways to detect foreign material for controlling, monitoring, and tracking foreign material in products. As the food industry continues to deal with an increase of foreign material contamination, the need to detect it becomes more important. It is imperative for food manufacturers to avoid foreign material in the finished product. In addition, food manufacturers need to consider what types of detection methods will be used and where they should be in the production system. Understanding the technologies will aid production facilities on how to use them for specific food products, and ultimately minimize the risk of physical hazards introduced through foreign material. Filtering and screening, metal detection, ultrasound technology, X-ray, and terahertz technologies were assessed for their usage and advantages and disadvantages. Filtering and screening use a type of barrier to remove foreign material from food products. Filters and screens are best used for dry or free-flowing products, but they are also helpful at the beginning of a production process. Metal detection is used for finding metal in food products. This technology has been shown to be highly effective and to work well with multiple processes. Ultrasound technology is a nondestructive detection method that uses thermal imagining to find differences. Ultrasound is effective for the dairy and nut industry, but it requires lots of time and data for initial set up. X-ray can detect different types of foreign material including metal and can be used for a variety of food products. Terahertz is like X-ray by using imaging to find the foreign material and is effective in meat products. The technologies reviewed can all be an effective method for detecting foreign material. Overall, X-ray was found to be the most effective detection method across all industries.

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Introduction

Foreign material is a potential food safety hazard that must be addressed by the food and meat industries as part of their food safety assessment. Multiple technologies have been developed over the years to drive detection of foreign material. Food suppliers, manufacturers, and processors are faced with the challenge of needing to produce food fast, but safely. Companies need to identify the most effective methods for controlling, monitoring, and tracking foreign material in products.

The United States Department of Agriculture (USDA) Food Safety Inspection Service (FSIS) defines foreign material as a non-animal object such as metal, wood, plastic, and rubber that may cause a physical hazard and would define the food product as adulterated and unfit for sale (USDA, 2003). The term "foreign material" refers to any unwanted objects in food, even if the material is a component of the same product (for example, bone in meat products or seeds in fruit products) (Graves et al., 1998).

All food producing plants are required by law to have a HACCP according to USDA FSIS Title 9 CFR 417 or Preventative Controls for Human Food plan according to FDA Title 21 CFR 117 Subpart C. These plans are based on minimizing the risk of physical, chemical, or biological hazards during the production process. Foreign material that causes injury or illness to a consumer would be considered a physical hazard and should be addressed in facilities hazard analysis. Title 9 CFR 417.2(a) for meat and poultry processing facilities and Title 21 CFR 117.130 for FDA facilities requires these processing facilities to conduct a hazard analysis to evaluate for food safety hazards. They must determine if hazards are reasonably likely to occur and identify preventive measures to control these hazards (USDA, 2003). One way to control physical hazards is using foreign material detection methods.

Finished products can become contaminated with foreign materials at any stage throughout production (Osuagwu, 2018). The most important factors food processors need to consider when selecting detection technology for foreign material are high detection ratio, high reliability, and real-time results (Kwon et al., 2008).

Foreign material can be hazardous to the consumer. Federal regulations define that objects that are hard or sharp and measures 7 mm to 25 mm in length are hazards (Consumer Packaged Goods Section 555.425). This regulation definition is in place because these items can cause larynx and oral cavity injuries, teeth damage, digestive tract tissue damage, internal bleeding, dysphagia, and regurgitation. Foreign material can also cause choking, suffocation, and even death (Trafialek et al., 2016). The regulatory definition according to Title 16 CFR 1500.19 states that choking hazard for the toy industry is an object that is a diameter of less than 3.175 centimeters and a length less than 5.715 centimeters. This size object is of concern because it could be caught in the throat blocking airways and making it difficult to breathe (Trafialek et al., 2016).

Besides being a health hazard, foreign material is an aesthetically unpleasing element in food (Osuagwu, 2018). Unlike biological and chemical hazards, consumers can easily understand that physicals hazards like glass, metal, and plastic should not be present in food products (Burd, 2007). Recently, there have been several recalls of food products due to the presence of foreign material. On August 14, 2022, frozen pizzas were recalled for metal contamination (FSIS, 2022). In addition, on May 4, 2019, 5,352,390 kilograms of frozen, ready-to-eat chicken strips were recalled for metal contamination (FSIS, 2019). The FDA also has food recalled for foreign material. On November 3, 2022, edible cookie dough was recalled due to soft plastic film presence (FDA, 2022). In addition, on August 24, 2022, animal cookies were recalled due to metal wire found (FDA, 2022).

This report will review foreign material trends and what detection methodologies are used by industry to detect or eliminate foreign material hazards. The detection methods that will be discussed are filtering and screening, metal detection, ultrasound technology, X-ray, and terahertz. Lastly, different product types and the difficulty they present when selecting a detection method will be discussed.

Review of the Literature

Foreign Material Trends in the Industry

The presence of foreign material in a product may result in a food recall. There are three types of food recalls including: class I where there is a reasonable probability that eating the food will cause health problems or death; class II where there is a remote probability of adverse health consequences from eating the food; and class III where eating the food will not cause adverse health consequences (USDA, 2006). In 2017, 10% of the recalls in the U.S. were due to foreign material, and this number continues to increase (Maberry, 2018). In the current world of social media and instant access to news, consumers have an easier time reporting food contamination. Regulating governments do their best to stay on top of the reporting to assure the safety to all consumers. Increased consumer knowledge and easier reporting ability also has led to an increase in the number of foreign material recalls (Burd, 2007).

Recalls cause issues including increased product costs, replacing product stock in stores, loss of customers, and possibly legal costs. Recalls can cost up to 1 billion dollars. The frozen chicken strips recall in May 2019 cost the producing company several million dollars (Wowak et al., 2021). Besides the financial impacts of a food recall, negative media presence can create damage to the brand (Burd, 2007). To reduce the possibility of a recall due to extraneous material, foreign material controls need to be in place and manufacturing facilities need to assess what would be the most effective detection methods for their products.

A year-by-year comparison of USDA published recall data from 2015 showed that the number of recalls in the U.S. represented a 315% increase from 2014 to 2015 due to adulterated products recalled for foreign material concerns. In 2015, 9,572,998 kilograms of food were recalled by the U.S. meat and poultry industry (Osuagwu, 2018).

According to Edwards and Stringer (2007), complaints associated with all types of foreign material have been noted with varying frequency. Table 1 shows the percentage of incidents and number of incidents of foreign materials in the United Kingdom from 2000-2004 associated with different commodities. There was a total of 2,347 cases, and complaints were mainly associated with vegetables and vegetable products which comprised 20.2% of the incidents, followed by cereals and cereal products with 12.8% of the incidents. The next highest was meat and meat products with 8.8% of the incidents (Edwards & Stringer, 2007).

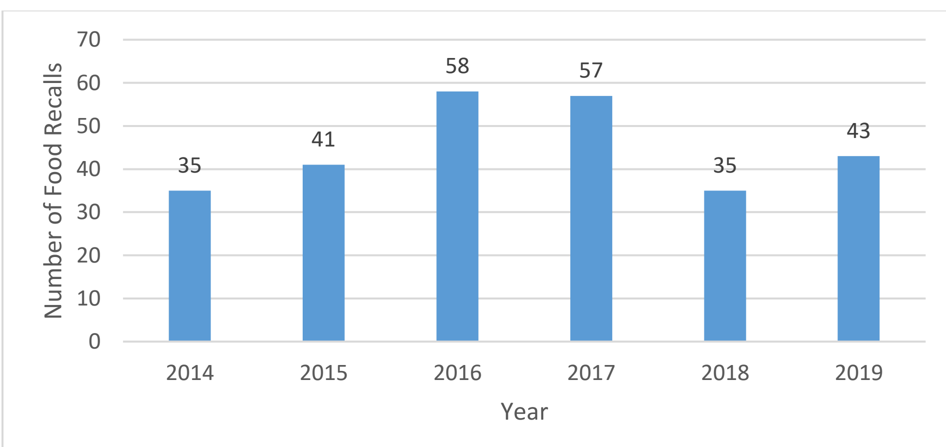
Table 1: Types of food associated with foreign material incidents from 2000 – 2004 in United Kingdom (From Edwards & Stringer, 2007).

Food Type	Percentage of Incidents	Number of Incidents
Vegetables and vegetable products	20.2	458
Cereals and cereal products	12.8	289
Meat and meat products	8.8	200
Ready meals	7.8	176
Milk and dairy products	5.1	115
Poultry and poultry products	4.8	109
Cocoa, chocolate, and confectionery	3.4	76
Fish, shellfish, and fish products	3.2	73
Baby food	2.9	66
Fruits and fruit products	2.6	58
Drinks	1.7	38
Textured meat substitute	1.5	35
Oil and fat-based foods	1.2	28
Noodles and rice	1.0	23
Eggs and egg products	1.0	22
Desserts	0.9	20
Acid base sauce	0.7	17
Soup	0.7	16
Nut, seed, and dried legume	0.6	14
Spice, dry soup, and flavor	0.4	10
Unknown	12.4	281

In comparison, a study conducted by Page (2018) evaluated the data for all USDA recalls including biological and chemical recalls, from 2004-2013. In reviewing the data, the number of incidents shifted from vegetable and vegetable products and cereals and cereal products to prepared foods and meals and nuts, seeds, and nut products. Prepared foods and meals comprised 11.86% of the foods recalled in the U.S., while nuts, seeds, and nut products were a part of 10.86% of the recalls. These percentages also included biological and chemical recalls that were also associated with these products. In comparing the study by Page (2018) to data evaluated by Edwards & Stringer (2007), the number of recalls associated with prepared foods and meals and nut products have increased over time. The shift in product types associated with recalls occurred around the same time as requirements for the Food Safety Modernization Act were announced. This regulation required all production facilities to evaluate their risk for foreign material. Facilities producing prepared foods and meals were already following HACCP plans, but their exposure to possible foreign material contamination is higher, possibly due to raw material contamination and equipment failures (Osuagwu, 2018).

In addition, a study conducted by Mohd et al. (2020) reviewed a total of 269 foods that were recalled between 2014 – 2019 due to the presence of physical hazards in Canada (Figure 1). The highest number of recalls occurred in 2016 with 58 recalls.

Figure 1: Number of food recalls due to physical hazards from the year 2014 – 2019 in Canada (From Mohd et al., 2020).



The study by Mohd et al. (2020) also compared recalls for each year between 2014 to 2019 in Canada based upon product type (Table 2). For example, there were 10 recalls in the grain and cereal product types in 2016 in Canada. A chi-square test was used in this study to provide statistically significant differences. This type of test is a hypothesis testing method used to test if the observed frequencies match expected frequencies. The – and + in Tables 2 and 3 are added if the observed value was lower (-) or higher (+) than the expected value (Mohd et al., 2020).

Overall, this study found there was no difference ($P \geq 0.05$) in the number of recalls for all food products except nuts and breads/bakery products. In 2015, there were a low number of recalls of bread/bakery products and recalls in 2018 and 2019 were low for nuts. The chi-square test predicted that 0 was lower than expected from the statistical evaluation. The food recalls associated with nut and bread/bakery products were due to the presence of plastic which can come from packaging materials, equipment, or pallets.

Table 2: Distribution of foreign bodies per year based on product type from 2014 – 2019 in Canada (From Mohd et al., 2020).

Product Type	**Year**						
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**
Grain and cereals	2	7	10	3	3	4	29
Fruit and vegetables	13	8	18	20	14	9	82
Dairy	1	5	2	7	3	3	19
Meat, poultry, and seafood	9	11	6	10	5	9	50
Nut	1	1	1	2	0(-)*	0(-)*	7
Bread and bakery	2	0(-)*	5	2	1	7(+)*	17
Wine and beverages	1	2	2	2	2	1	10
Candy and confectionery	1	3	2	7	3	2	20
Other food products	5	4	12	4	4	8	35
TOTAL	**35**	**41**	**58**	**57**	**35**	**43**	**269**

*The effect of the chi-square per cell. (+) or (-) indicates that the observed value is higher or lower than the expected theoretical value. Significant level $\alpha<0.05$.

Mohd et al. (2020) also described what types of foreign material contamination were found in specific product categories in Canada between the years of 2014 through 2019 (Table

3). Within the dairy product category, plastic contamination was more prevalent ($P \leq 0.05$) than bone, rubber, wood, and stone. Plastic contamination was the cause of 47% of the recalls associated with the dairy products industry. Meat, poultry, and seafood products had a higher ($P \leq 0.05$) incidence for bone and a lower ($P \leq 0.05$) incidence for glass and stone. Meat, poultry, and seafood had an 82% higher incidence rate of bone than other commodities. Bone has a higher chance in these types of products because bone could originate from the raw material itself as compared to the other commodities.

For breads and bakery products, a lower incidence rate overall was observed for rubber, wood, stone, and unknown objects compared to the other categories. Breads and bakery products have a low amount because there is a low risk for raw material contamination. This occurs from the ingredients being prescreened prior to entering bread or bakery producing plants (Motarjemi & Lelieveld, 2013). Breads and bakery products are mostly concerned about plastic contamination. Wine and beverages were noted to have a higher ($P \leq 0.05$) incidence for glass items, and there were no reports of plastic, bone, rubber, wood, or stone. Glass most likely came from the packaging material (Mohd, 2020).

Table 3: Distribution of physical hazards incidences according to product and foreign material type in Canada for the years 2014 – 2019 (From Mohd et al., 2020).

Product Types	Foreign bodies								
	Metal	**Plastic**	**Glass**	**Bone**	**Rubber**	**Wood**	**Stone**	**Unknown**	**Total**
Grains and cereals	6	2	2	2	1	0(-)*	1	1	15
Fruits and vegetables	7(-)*	5(-)*	2(-)*	0(-)*	3	0(-)*	0(-)*	9	26
Dairy	5	8(+)*	1	0(-)*	0(-)*	0(-)*	0(-)*	3	17
Meat, poultry, and seafood	13	10	0(-)*	9(+)*	2	2	0(-)*	4	40
Nut	0(-)*	3	0(-)*	0(-)*	0(-)*	0(-)*	0(-)*	0(-)*	3
Breads and bakery	3	5	1	0(-)*	0(-)*	0(-)*	0(-)*	0(-)*	9
Wine and beverages	1	0(-)*	5(+)*	0(-)*	0(-)*	0(-)*	0(-)*	2	8
Candy and confectionery	6	7	0(-)*	0(-)*	1	1	0(-)*	1	16
Other food products	5	5	7 (+)*	0(-)*	0(-)*	2	1	3	23
Total	46	45	18	11	7	5	2	23	226

*The effect of the chi-square per cell. (+) or (-) indicates that the observed value is higher or lower than the expected theoretical value. Significant level $\alpha<0.05$.

Recalls associated with foreign material can be minimized by focusing on detection methods. Detection methods are important for all food product types (Trafialek et al., 2016). Several technologies and techniques have been used to detect foreign material such as filtering, screening, metal detectors, ultrasounds, X-rays, and terahertz.

Where Detection Methods are Needed

One consideration that needs to be addressed when employing detection methods is where the detection methods should be employed in the production process. Trafialek et al. (2016) conducted a risk analysis to review foreign material in a production facility, especially for metal contamination. The study focused at one plant in Poland with 50 people employed. The study evaluated cereal products, dried fruits, dried vegetables, legumes, nuts, sugar, and confectionery products. The authors wanted to identify where foreign material was found and then where detection technology should be placed in the production process. Throughout the study, 862,800 products were evaluated. Even though this study involved only one plant, it can provide a broad understanding to where detection methods are needed in food manufacturing plants.

In another study conducted by Osuagwu (2018), it was identified that the highest risk for foreign material occurred during receiving. Raw materials brought in could be contaminated from a supplier or within transportation (Osuagwu, 2018). To address the concern of foreign material at receiving, a metal detector should be utilized at the beginning of the process. Additional risks that were identified included poor use of production tools, equipment failures, and employee negligence (Osuagwu, 2018).

While other risks such as equipment damage and employee practices occur within the process, the risk assessment completed by Trafialek et al. (2016) did not identify these as being the highest risk. Trafialek et al. (2016) identified that metal detection should be used at the final packaging step. The final packaging metal detector would determine whether any contaminants had entered the product during production. Their research did not focus on the types of detection, but where it might be used within food manufacturing. Their research provides a good start to understand foreign material contamination in production facilities.

Before discussion of different detection methods, it should be noted that these methods do not eliminate foreign material. Rather, this can identify a contaminant so it can be removed. Detection methods will not be 100% effective, and there are still chances for foreign material to remain in the product. Foreign material can be found in food because of contamination of raw materials, improper control during receiving, improper production practices, employee negligence, and old or broken equipment. The potential sources for these foreign material events mostly come from equipment, facilities, and cleaning tools (Ogawa et al., 1998).

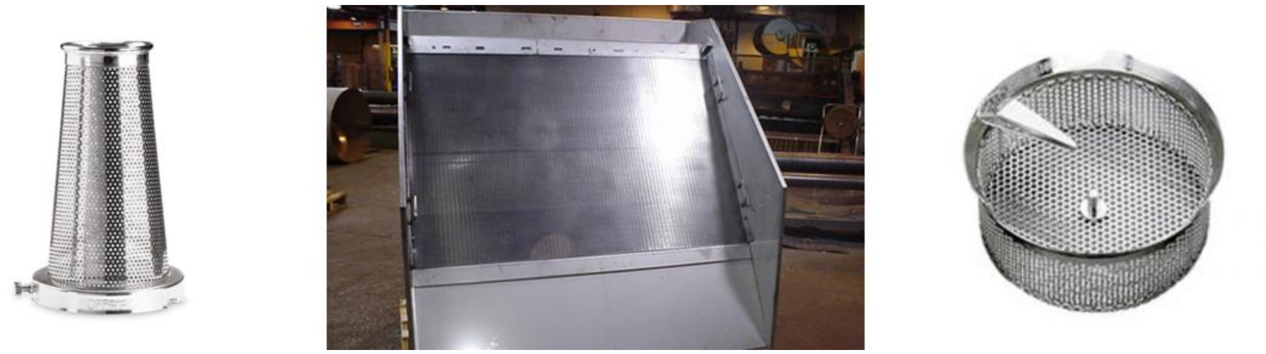
In addition, it is important to note that the type of packaging can affect foreign material detection methods ability. As more packaging is added outside of the primary packaging, it will be more difficult for any type of detection method to identify foreign material contamination. The less packaging, the higher the chance the detectors have in finding the contaminate (Edwards, 2004).

Each foreign material detection method has advantages and disadvantages, and it is difficult to satisfy the food industry by choosing a particular method due to the complexity and diversity of food compositions (Wang et al., 2019). Other factors such as waste and cost may have a considerable influence on which method food producers will choose to implement in a facility (Osuagwu, 2018). One key concept for detection methods is to be non-destructive (Ogawa et al., 1998). Advantages and disadvantages of selected foreign material detection methods and their usage in specific food products is discussed in the following sections.

Filtering and Screening

Filtration or screening may be used to remove foreign material. Screens can separate solid from liquids or separate solids from solids based upon size. Some screens systems require mechanical agitation or a type of moment to allow for products to flow, but the basic method is creating a physical barrier that can possibly remove foreign material (Motarjemi & Lelieveld, 2013). Filters and screens can be used in food production by either being part of the process that the product will pass through like piping, or some products can be dumped on top of the screen. Screens are made of a type of grid that product will pass through. The grid is most commonly composed of metal (Motarjemi & Lelieveld, 2013). Figures 2 provides examples of screens used in the industry

Figure 2: Examples of screens and filters used in the food industry (From LEM products, 2022 and Hendrick Manufacturing, n.d.).



Sieve filtering may be used to screen foreign material. These have been identified as the most effective method for powdered and flowing products (Mohd et al., 2018). Screening, sifting, and filtering are basic foreign material detection methods that are also effective and cost efficient (Dumas, 2018).

The advantage of this technology is low cost and high effectiveness. One disadvantage is screens and filters can wear out and break over time. To minimize this, they must be inspected regularly and replaced following a standard operating procedure before they become a source of contamination and introduce metal themselves into the system (Motarjemi & Lelieveld, 2013). For these reasons, additional steps are needed in a process for additional control of foreign materials.

Metal Detection

Metal detectors are used to detect metal and are highly effective. Metal detection uses electromagnetic induction to detect foreign material (Yamazaki et al., 2002). A basic metal detector works with one transmitting coil in the center of the aperture and two receiving coils on sides. The transmitting coil is what detects when metal is found (Yamazaki et al., 2002). Metal detectors are generally used where food products travel on a conveyor belt and travel through a metal detector. When metal is detected, the belt will stop, or product will be kicked off the line. This technology then relies on an operator to remove the contaminant (Dumas, 2018). Figure 3 provides examples of metal detectors for prepared foods and meat industries. For these examples, the belt would stop when foreign material is detected.

Figure 3: Examples of metal detectors used in the food industry (From CEIA, 2022 and Refrigerated & Frozen Foods, 2019).

Typically, three types of metal are used for calibration and can be commonly found in production facilities. These types of metal are ferrous, non-ferrous, and stainless steel. The goal of metal detection is the ability to detect at the smallest level for each of the three types of metal (Yamazaki et al., 2002). A common setting used for metal detection would be 1.5 mm ferrous, 2.0 mm non-ferrous, and 2.5 mm stainless steel. These parameters help determine what the transmitting coil will be able to detect (Liu & Zhou, 2011). Food products that have a higher conductivity level, such as frozen items, can be more difficult to find metal in with coiled systems (Graves et al., 1998).

Metal detection is the most common and basic technology used for foreign material detection (Dumas, 2018). Metal detection can be used across all food industries and is commonly found in production facilities. There is hope for improvements in the level of detection, accuracy, and speed of metal detection, while keeping the technology cost effective (Dumas, 2018). One example where metal detectors are a concern is with aluminum can product processing facilities. Technology is needed to ensure that the metal inside of the can is detected versus the metal can (Graves et al., 1998).

In addition, there are some limitations to metal detection. Depending upon the size of the product, the height of the equipment and the distance away from the detector will affect the ability of the metal detector to identify foreign material. The sensitivity is proportional to the height of the aperture the product will pass through. The distance away from the detector will also affect the sensitivity because the product signals could cross if product gets too close to the top (Edwards, 2004).

With that being said, the size and amount of packaging will also affect the effectiveness of metal detections. To maximize metal detection abilities, this type of technology should be used with the primary packaging. As food product enter secondary and tertiary packaging, it will be more difficult for metal to be found by the metal detector (Edwards, 2004).

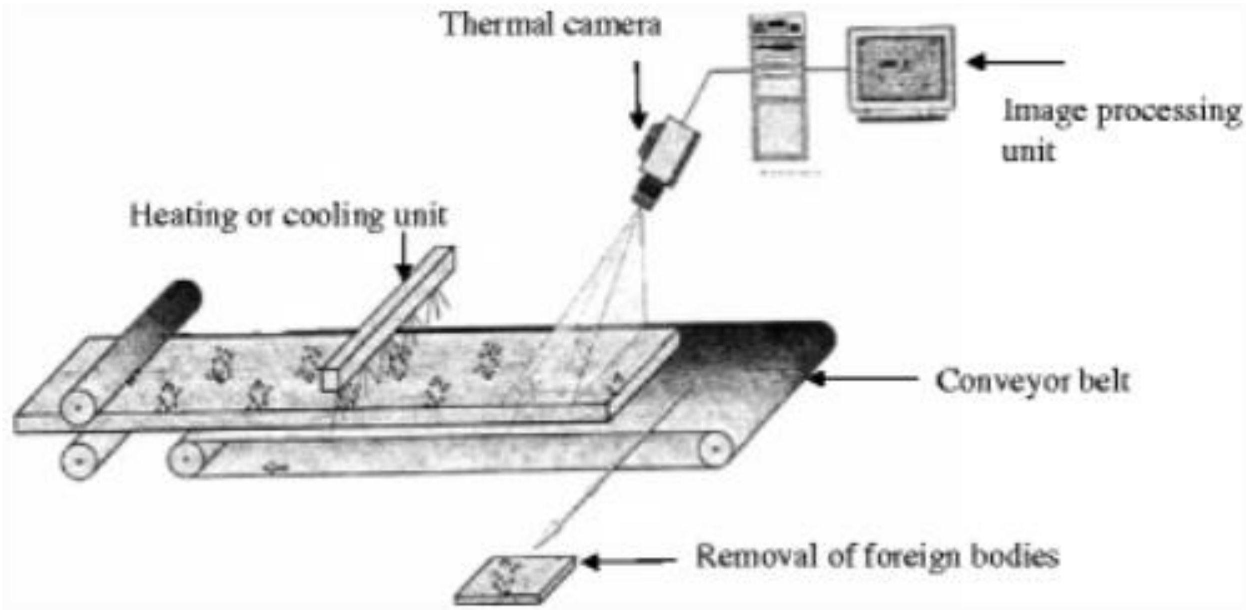
There are some disadvantages that need to be improved for metal detection to be an effective foreign material detection method. An increase in the frequency of the metal detector signal is needed to improve sensitivity and have the greatest chance of finding metal foreign objects in food products (Liu & Zhou, 2011). One limitation with metal detectors is their compatibilities to the material that is being tested and the target type of metal. In addition, metal detectors can only detect certain metals, such as ferrous, non-ferrous, and stainless steel. They cannot detect plastic, wood, or rubber (Yamazaki et al., 2002).

Ultrasound Technology

Ultrasound technology is a type of thermal imaging that works with all objects above 0 K to emit infrared rays which makes the objects part of the electromagnetic spectrum. Ultrasound works by converting radiation from an object into temperature without establishing contact with the object. The sample is heated up by the detector element, so the radiation in the object can fall and be shown in the computer system (Vadivambal & Jayas, 2011). There are two different ways that ultrasound technology can detect for foreign material. Those two ways are either by differing emissivity or by using different heat conductivities of the food product (Ginesu et al., 2004). Figure 4 provides an example of a set up for ultrasound technology.

Ultrasound technology works by food products traveling along a conveyor belt and then being exposed to the heating or cooling element. The differing temperature will cause a different behavior on the possible foreign material versus the food product. Because of their different heating conductivities, the foreign material and food product will heat up or cool down at different speeds (Ginesu et al., 2004). At this time, a thermal camera will collect a series of images to observe the temperature changes. These images will be transferred to a computer for software that has an image processing unit. Then, the image will displace the temperature differences for identification of possible foreign material contamination (Vadivambal & Jayas, 2011).

Figure 4: Set up for ultrasound technology use in the food industry (From Vadivambal & Jayas, 2011).



Ultrasound technology is a noninvasive detection method. The type of frequency used with ultrasound will determine the overall effectiveness of this technology. The higher the frequency used by the unit, the smaller the size of foreign material that can be detected (Mohd et al., 2018).

One advantage of ultrasound technology is that it is a noninvasive, noncontact, nondestructive, and rapid technique (Vadivambal & Jayas, 2011). Depending upon which imagining equipment is obtained, this technique can be low cost and comparable to X-ray (Yin et al., 2020).

Mohd et al. (2018) evaluated the use of ultrasound technology in refrigerated milk. Milk is unique because the product is not transparent, and the packaging used for milk is not always opaque plastic. Metal and plastic fragments can be present within milk production. Some foreign objects enter the product stream due to poor manufacturing practices, machine parts, or packaging equipment (Mohd et al., 2018).

Mohd et al. (2018) used polyethylene, wood, metal, plastic, and glass of various densities to evaluate ultrasound technology in refrigerated milk (Table 4). Speed of sound and acoustic impedance with these items were also monitored as they are important to detecting foreign material using ultrasound. The speed of sound through milk is 1548 m/s. It was calculated that the minimum diameter of foreign objects that can be detected by a frequency of l MHz and 300 kHz, respectively, was 1.5 mm and 5.2 mm (Mohd et al., 2018).

Table 4: Values of density, speed of sound, and acoustic impedance of foreign objects used to evaluate ultrasound technology in milk (From Mohd et al., 2018).

Material	Density, ρ (kg/m^3)	Speed of sound, c (m/s)	Acoustic impedance, Z (10^6 kg/m^2s)
Polyethylene	900	1950	1.76
Wood (soft)	450	3600	1.62
Wood (hard)	722	3850	2.78
Milk	1037	1548	1.61
Metal	8060	5800	46.75
Plastic	1537	2395	3.68
Glass	1199	2750	3.30
Wood	722	3850	2.78

Sixteen ultrasonic transmitters were placed outside of a milk carton. The objects listed in Table 4 were placed into the carton of milk, and then the carton was exposed to the ultrasound equipment to determine if these objects could be detected. The ultrasound technology could detect all the types of materials that were evaluated in this study (Mohd et al., 2018).

The results from Mohd et al. (2018) demonstrated that ultrasound may be successfully used to detect a variety of foreign materials used in liquid products. Ultrasound machine components also are found to be less expensive than X-ray (Mohd et al., 2018). As a result, ultrasound technology should be considered for milk producers. To expand application of this technology to other types of food products, more research would need to be conducted.

In research completed by Ginesu et al. (2004), almonds and raisins were contaminated with pieces of wood, stone, metal, and cardboard to determine if these foreign objects could be detected using ultrasound technology. The test involved manipulating the images of the contaminated products to find the foreign objects. The manipulation was completed by removing backgrounds and slowly adding parts of the image back into view. This study determined that ultrasound technology was able to detect all the tested foreign objects. This is another example where research demonstrated that ultrasound technology works for detecting foreign objects; however, the amount of time and number of images needed to support these results was costly.

This experiment, for example, required 500 images to evaluate 10 test samples (Ginesu et al., 2004). Images collected from this technology go through a series of steps before foreign material can be identified. The first step is a dead pixel correction, followed by an enhancement filter application, and then a second enhancement filter application. The final two steps are shading correction and histogram stretching. These five steps must be done before ultrasound can identify foreign material in the food products. These steps can take time, which makes ultrasound technique costly (Ginesu et al., 2004).

Due to the speed and wavelengths that may be incorporated in ultrasound technology, there are many potential avenues through which ultrasound may be helpful in the future. Some of the disadvantages to this method are the large amount of data that is needed be collected and the additional research that will be needed to be applicable to industry use (Yin et al., 2020). Approximately 50 images per foreign material object need to be collected and manipulated to find the contaminate in tested food products (Ginesu et al., 2014).

X-ray

X-rays use high powered energy sources and imaging systems to produce images of the product and identify foreign materials in packaged goods. This equipment works in three different steps, which are absorption, phase contrast, and dark-field imaging. The phase grating step controls the beam direction. As the beam penetrates the food product, it loses some of its energy. During the scanning process, absorption, refraction, and scattering are recorded by the detector to produce an image. The sensor converts the energy signal into an image. (Einarsdóttir et al., 2016). X-ray technology uses shortwave lengths to pass through package materials to detect for foreign material. Foreign material found by X-ray will appear a darker shade than the food product. An example of an X-ray set up for a producing plant is shown in Figure 5 (Einarsdóttir et al., 2016). Figure 6 shows examples of what actual X-rays look like in the food industry (Lab, 2012 and Lind, 2014).

Figure 5: Examples of X-ray set up in the food industry (From Einarsdóttir et al., 2016).

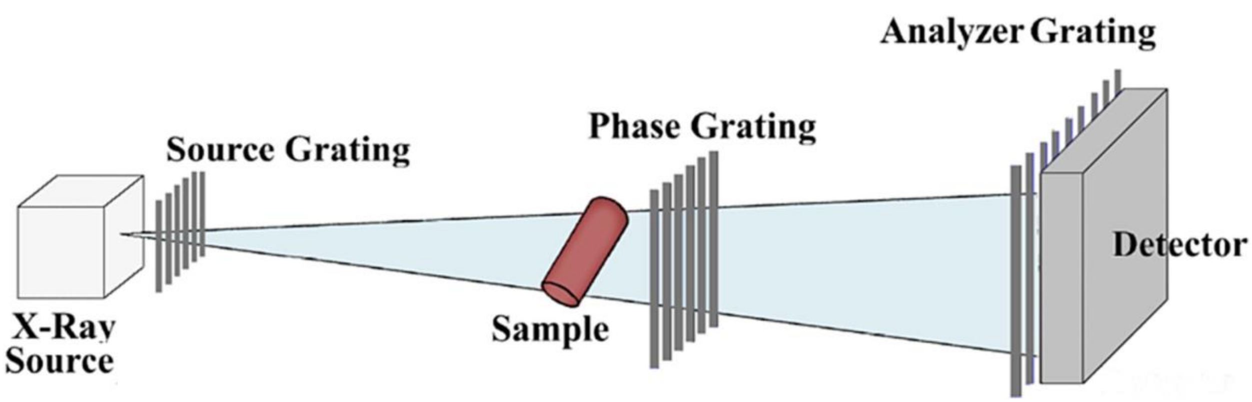


Figure 6: Examples of X-rays the food industry (From Lab, 2012 and Lind, 2014).

An experiment completed by Nielsen et al. (2013) examined the possibility of X-ray being able to find a folded sheet of 215.9 mm by 279.4 mm piece of paper and a 1 mm thick piece of glass in minced meat and sour cream. These two food products were chosen as examples for the meat and dairy industry (Nielsen et al., 2013). Nielsen et al. (2013) found that the objects were harder to find in minced meat as compared to sour cream. There have been issues with finding foreign material in fibrous structures, such as minced meat, which was also the case in this study. Fibrous structures and textured food make it difficult to find foreign material as their images do not allow foreign material to not stand out enough or be distinctive.

Kwon et al. (2008) evaluated how to detect foreign material objects in irregular texture patterned food products. These researchers focused on manipulating X-ray imaging to create a way to view the foreign material. Their study used a total of 170 images in three types of packaged dry foods including instant ramen, macaroni, and spaghetti. The foreign material objects used were a stainless-steel ball, Teflon ball, aluminum ball, rubber ball, glass ball, ceramic ball, and stainless-steel wire. These objects had a variety of sizes ranging from 0.3 to 8 mm (Table 5).

Table 5: Foreign material types, density, and sizes used to test X-ray capabilities (From Kwon et al., 2008).

Type	Density (kg/cm)	Size (mm)					
Stainless Steel Ball	7.93	1	1.2	1.5	2	2.5	3
Teflon Ball	2.18	3.2	4	5	6	7.2	8
Aluminum Ball	2.78	2	3	4	5	6	7
Rubber Ball	1.30	3	4	5	6	7	8
Glass Ball	2.49	2	3	4	5	6	7
Stainless Steel Ball	7.93	0.3	0.4	0.5	0.6	0.7	0.8
Ceramic Ball	3.90	2	3	4	5	6	8
Stainless Steel Wire	7.93	0.2×2	0.3×2	0.4×2	0.5×2	0.6×2	0.7×2

This study was completed by first removing the background on the image. Then, a positive response of the zero mean was utilized to enhance the foreign material image. Finally, the max-min difference of the sub-regions were used to show the foreign material in the primary cardboard package of the dry foods (Kwon et al., 2008).

High density materials, like stainless-steel balls, aluminum balls, glass balls, and ceramic balls were detected at a 98% rate without false positives. In contrast, low density materials including the Teflon ball and rubber ball had a low detection rate (Kwon et al., 2008). The detection ability of the foreign objects in packaged food containing high texture patterns such as macaroni was lower than that in packaged foods containing a low texture pattern such as spaghetti or ramen (Kwon et al., 2008).

Research completed by Einarsdóttir et al. (2016) evaluated which items might be most difficult to detect using X-ray. They evaluated the efficiency of X-ray technology across seven different food products using a range of foreign material objects. The seven food products were minced meat, steak, turkey schnitzel, sliced salami, sliced cheese, wheat bread, and rye bread. This experiment used only the food products and no packaging, and covered products from meat, dairy, and grain food categories. The objects included glass, metal, wood, plastic, rubber, and stones ranging in size and density (Table 6). Figure 7 shows pictures of the type of the materials that were being tested from Table 6.

Table 6: Type, density, and thickness of foreign material objects used to test X-ray detection (From Einarsdóttir et al., 2016).

Type	Density	Thickness (mm)		
Glass	2.62	5	3	2
Metal	3.82 – 7.82	2	1	0.5
Wood	0.63	6	4	2
Hard Plastic	0.66	6	3	2
Soft Plastic	0.30	5	3	2
Rubber	1.21	4	3	2
Stones	2.23 – 2.50	6	4	3

Figure 7: Visual of foreign material objects type and size used to test X-ray detection (From Einarsdóttir et al., 2016).

The results from Einarsdóttir et al. (2016) demonstrated how efficiently X-ray detection could be done for each item. It was determined that for food products that had more texture, it was more difficult to find the foreign objects using X-ray technology. Soft plastic and wood were the most difficult for detection by X-ray. Soft plastic and wood are difficult to detect because they do not stand out from food products in an X-ray. Wood can have similar texture as meat.

The inability to detect soft plastic and wood provide limitations to being able to use X-ray across the entire food industry. In comparison, metal, glass, and stone were the easiest object types for X-ray to detect. The limitations of X-ray technology are cost, processing speed, and worker safety aspects (Einarsdóttir et al., 2016).

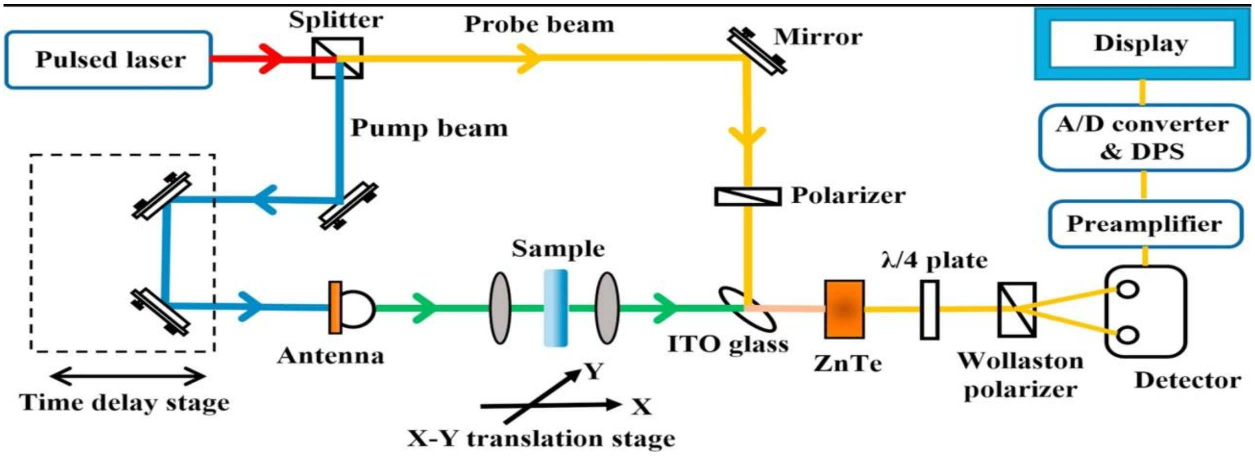
The ability of X-ray devices to differentiate even small differences between food and foreign material makes X-ray technology more effective. In addition, this ability to detect small differences makes X-ray better in detecting metal than metal detectors. X-rays can even detect for smaller metal pieces than possible with a metal detector. In addition, X-rays have been able to identify bones, plastic, glass, and other types of foreign material (Dumas, 2018).

X-ray has a limitation in detecting low-density materials like plastic. X-ray also is not always preferred because it can cause a radiation hazard and is costly (Mohd et al., 2018).

Terahertz

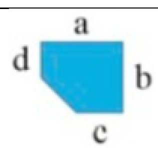
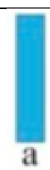
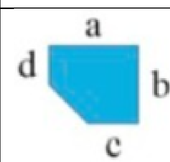
Terahertz spectroscopic imaging is like using X-ray imaging, but it does not use ionizing with the photon energy. Figure 8 is an example of what the set up would look like for this type of technology. The stage was located on the beam path between the two lenses, allowing for the sample to move in the focal plane and into scanning view. The imagining area, step resolution, and moving speed is controlled by a computer with imaging software. The motorized stage will move, and then the image is recorded (Wang et al., 2019).

Figure 8: Layout of terahertz technology for use in the food industry (From Wang et al., 2019).



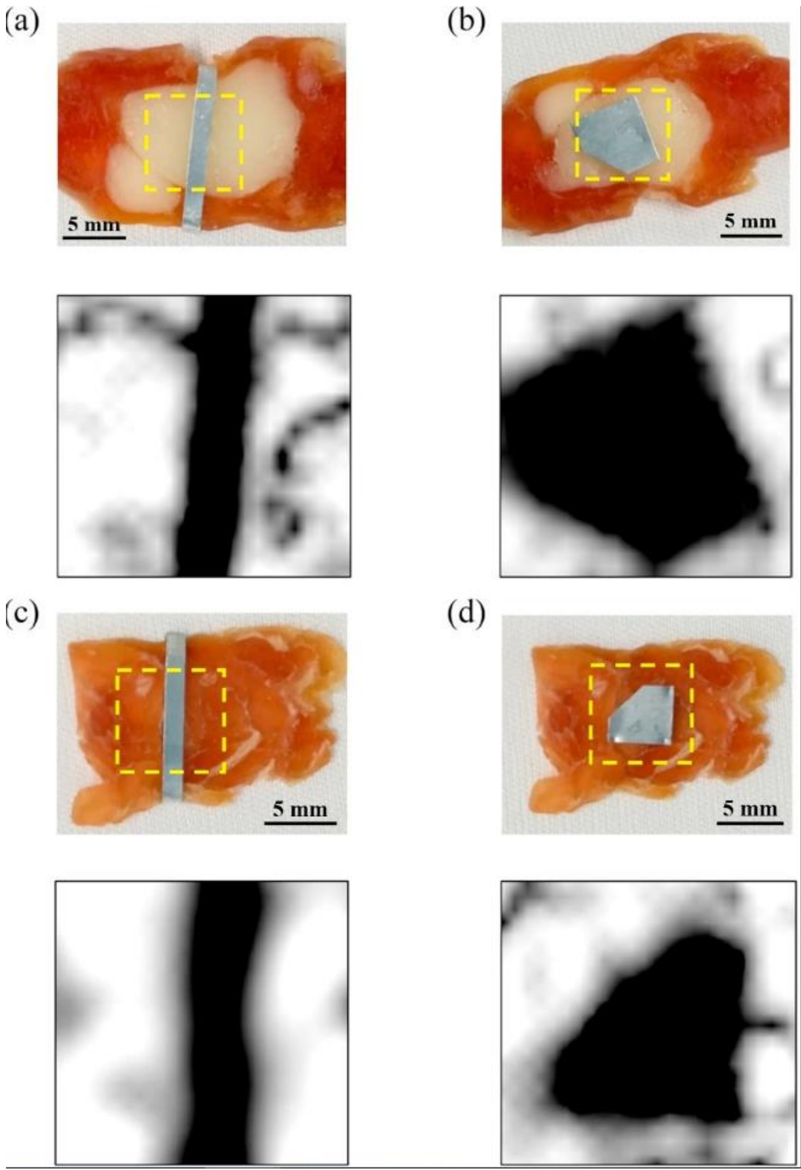
Wang et al. (2019) used pork sausage product samples to test the effectiveness of terahertz spectroscopic imaging, a non-destructive technology. They placed aluminum sheets with polygon and strip shapes of different sizes and lengths into pork sausage samples. Each aluminum sheet shape (polygon and strip) was placed specifically in the fat or lean parts of the sausages. The fat and lean pork sausage samples were 1 and 2 mm. The specific sizes of those shapes are shown in Table 7.

Table 7: Sizes of the aluminum sheets used for test and where in the meat it was placed (From Wang et al., 2019).

Size (mm)	Polygon in fat	Strip in fat	Polygon in lean	Strip in lean
				
a	6	1.4	5	1.4
b	6		4.5	
c	3		2.5	
d	2.5		2	
Thickness	0.08	0.08	0.08	0.08

Wang et al. (2019) found that fat had a higher absorption rate than lean which implies that foreign material in the fat was more easily detected by terahertz technology. It was also found that this technology is an effective way to find foreign material objects in sausage. The imagining was able to identify the foreign material with all sets of samples. Figure 9 shows where the piece of aluminum was placed in the sausage sample and then what images were developed from the ultrasound.

Figure 9: Ultrasound images from testing aluminum sheets in pork sausage samples (From Wang et al., 2019).



Packaging material such as plastic, cloth, and paper are transparent in this imaging system, making this type of detection possible for products in these types of packaging. There are some improvements that need to be made to this technology before it can be widely used by industry, including increased timing of manipulating the images, robustness to interface, and ease of use for operators (Wang et al., 2019).

Conclusions

As the food industry continues to deal with foreign material contamination, the need to detect it continues to be important. Inadequate detection of foreign material will lead to potential consumer safety or quality concerns, and worst-case scenario product recalls.

Filtering and screening, metal detection, ultrasound, X-ray, and terahertz technology are effective methods for foreign material detection depending on the substrate being evaluated. Screening is best for powdered or small particle size products. There are concerns with filters and screens being able to catch the foreign material as it can get pushed through in the process. In comparison, metal detection is not the best choice for any industry. Most industries will pick this technology because it is cost effective. Metal detection is not favorable because that technology can only detect metal and not other types of foreign material.

For the meat industry, terahertz could be a good option, but this technology is not ready to be used. The wide range of foreign material objects that terahertz can detect makes it a desired technology for the meat industry. The issue would be the amount of time required for manipulation of images, and this technology is not ready to be widely used in the meat industry. At this time, X-ray would be favorable for the meat industry. X-ray would be the option for the meat industry with its ability to find plastic, metal, bone, rubber, paper, and glass.

Not widely used by the food industry is ultrasound technology, but it has proven research application in the dairy industry. More testing is needed to see if this type of technology could be expanded to the meat industry. Ultrasound technology can detect foreign material of concern, such as plastic, wood, metal, plastic, and glass, is noninvasive, rapid, and comparable in cost to X-ray technology.

For the dairy and grain industry, X-ray would be the best method because of its ability to detect all types of foreign material such as metal, plastic, rubber, paper, and glass. X-ray is the most effective method for foreign material detection, but it does have its own limitation with costs. Overall, X-ray was found to be the most effective detection method across all industries.

More research and in production facility testing are needed on foreign material detection methods. This additional research would be important to understand food processing industry wide and minimize the risk of foreign material in finished products.

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