

FOOD SCIENCE AND TECHNOLOGY

Lecture53

Lecture 53: Advanced Instrumentation and Sensors

Hello everyone! Namaste!



In today's class, which is lecture 53, we will discuss advanced instrumentation and sensors, particularly the instruments and sensors used in food processing, especially in food manufacturing and the supply chain.

The slide is titled "Concepts Covered" and lists the following topics:

- Introduction to sensors and instrumentation
- Types of sensors used in food manufacturing
- Instrumentation in food processing
- Real time data acquisition and processing

A small image of a sensor is shown in the top right corner. A small video inset in the bottom right corner shows Professor H N Mishra speaking.

So, we will discuss that is, we will talk about some introduction to sensors and instrumentation, types of sensors used in food manufacturing, instrumentation in food processing, and finally, we will study real-time data acquisition and processing.

Introduction to sensors and instrumentation

- Sensors and instrumentation play a pivotal role in modern food manufacturing, transforming how food is processed, monitored, and controlled.
- By integrating advanced technologies, these tools ensure precision, consistency, and adherence to strict quality and safety standards.

Sensor	Instrumentation
<ul style="list-style-type: none"> ✓ A device that detects and measures different parameters, converting them into signals. ✓ Captures specific data (e.g. Temperature, pressure) from the environment. ✓ Typically consists of a sensing element and a transducer. ✓ Acts as the primary source of data acquisition. <p>Example: A thermocouple measuring temperature.</p>	<ul style="list-style-type: none"> ✓ The collective arrangement of devices and systems used to monitor, measure, and control processes. ✓ Processes, analyzes, and utilizes data from sensors to manage and control operations. ✓ Includes sensors, transmitters, controllers, display units, and actuators. ✓ Integrates data from sensors to provide actionable information and control mechanisms. <p>Example: A complete temperature control system regulating a furnace.</p>

So, these sensors and instrumentation, I hope you know very well, play a pivotal role in modern food manufacturing. transforming how food is processed, monitored, and controlled. By integrating advanced technologies, these tools ensure precision, consistency, and adherence to strict quality and safety standards. A sensor can be a device that detects and measures different parameters, converting these parameters into signals. It captures specific data, such as temperature, pressure, and other such data from the environment. It typically consists of a sensing element and a transducer, and it acts as a primary source of data acquisition. For example, you can say that it is a thermocouple which is used in measuring temperatures online. Then, instrumentation is the collective arrangement of devices and systems which are used to monitor, measure, and control the processes. Processes, analyses, and utilises data from sensors to manage and control operations, that is, these instruments. This instrumentation includes sensors, transmitters, controllers, display units, actuators, and so on. It integrates the data from sensors to provide actionable information and control mechanisms. An example of an instrument can be a complete temperature control system in a furnace regulation system. i.e. there is a system that may contain one sensor, which is a temperature recording sensor, but along with it, there is a mechanism provided that will also control the temperature and keep it at a set position. So, that becomes the instrumentation.

Sensors

- A sensor is a device that detects and responds to physical, chemical, or biological stimuli by converting them into measurable signals.
- It plays a critical role in modern food processing industries by ensuring quality, safety, and efficiency at every stage of production.
- Sensors provide real-time monitoring and data acquisition to optimize processes, reduce waste, and meet regulatory standards.

Seal detection for small pieces in the film seals Detecting presence of cookies and pass/failure

So, now let us see what are the different types of sensors. A sensor is a device, as I told you, that detects and responds to physical, chemical, or biological stimuli by converting them into measurable signals. It plays a critical role in the modern food processing industry by ensuring quality, safety and efficiency at every stage of production. Sensors provide real-time monitoring and data acquisition to optimise processes, reduce waste and meet regulatory standards. For example, you can say here that in the conveying lines in the food processing industry, it detects small pieces in the film seal to determine whether the seal is properly maintained or there is a leakage, etc., or if the seal is proper or not, which can be identified using these sensors. Also, there are sensors which can detect the presence of cookies, and then, like here, there is a system, there is a cookie, all right, and there is an upper cookie, a lower cookie, and in between there is cream. So, the sensor will detect all three, and then you will see in the second case that there is no upper cookie. So, it will result in failure. In the third case, there is no middle cream.

Roles of sensors in food processing

Quality control	Sensors ensure the consistency of product characteristics such as texture, flavor, and appearance. <i>Examples: Temperature sensors, Spectroscopic sensors</i>
Safety monitoring	Detect potential hazards like contaminants, spoilage, or microbial growth. <i>Examples: Gas sensors, Biosensors</i>
Food manufacturing	Improve manufacturing production using the controlling of the stable condition. <i>Examples: Flow sensors, Pressure sensors</i>

So, these are various purposes for which these different sensors can be used. So, basically, the role of sensors in food processing can be used for quality control, such as sensors like temperature sensors, spectroscopic sensors, etc. They can be used to ensure consistency of product characteristics such as texture, flavor, appearance, etc. There are various sensors like gas sensors, biosensors, etc., which can detect potential hazards like contaminants, spoilage or microbial growth. So, these are called safety monitoring sensors. Then the sensors that can be used are helpful in food manufacturing, like flow sensors, pressure sensors, etc. So, they can be used to improve manufacturing production by controlling stable conditions.

Roles of sensors in food processing (Contd...)

- Freshness assessment**
Sensors detect freshness markers (e.g. volatile organic compounds or pH changes).
Examples: pH sensors, Humidity sensors
- Waste reduction**
Early detection of product defects and efficient process control reduce material wastage. Done by sorting the defective products automatically.
Examples: Optical sensors
- Automation and smart systems**
Enable Industry 4.0 with sensors that integrate into IoT systems for real-time monitoring and automation.
Examples: Wireless sensors, RFID sensors

The slide also features a small video inset of a man speaking in the bottom right corner and the NPTEL logo in the bottom left corner.

Then there may be sensors for freshness assessment, like pH sensors, humidity sensors, etc. They can detect the freshness markers, they can detect the various volatile organic compounds or changes in the pH on the basis of which they can say that yes these materials are spoiled or old, then the sensors like optical sensors or such other sensors can also be used for wastage reduction like early detection of product defects and efficient process control the material wastage and these are the these are done by sorting the defective products automatically. Then sensors can be used for automation and managing the smart systems that enable industry 4.0, with sensors that integrate into IoT systems for real-time monitoring and automation. And, this can be wireless sensor RFID sensors and so on.

So, if you want to classify these different types of sensors, alright, because they are very vital components and they have different applications and usefulness. So, it is always desirable that these sensors be classified on the basis of their applications. And, in that case, on the basis of their application, they can be classified as physical sensors, chemical sensors, or biological sensors. Physical sensors may include temperature sensors, pressure sensors, flow sensors, humidity sensors, proximity sensors, optical sensors, and so on.

Types of sensors

- Sensors in food industry has become a vital component for controlling the quality of food products and its efficient production without involvement of the human interaction.
- Different sensors has different application and usefulness, so it is important to characterize them based on application.

Sensors	Physical	Temperature sensor Humidity sensor	Pressure sensor Proximity sensor	Flow sensor Optical sensor
	Chemical	pH sensor Enzyme-based sensors	Gas sensor Adulteration detection	Electrochemical sensors
	Biological	Pathogen detection Toxin detection	Allergen detection Freshness detection	



Biological sensors may be those sensors that detect pathogens, allergens, or toxins, or for freshness detection. Chemical sensors may include pH sensors, gas sensors, electrochemical sensors, enzyme-based sensors, or adulteration detection sensors.

Physical sensors

- These sensors measure physical parameters such as temperature, pressure, flow, and humidity, playing a crucial role in ensuring quality, safety, and efficiency in food processing.
- Temperature sensors**
These sensors measure temperature to ensure processes like cooking, freezing, and pasteurization are carried out under optimal condition.

- ✓ **Thermocouples**
Used in ovens for baking and roasting.
- ✓ **Resistance temperature detectors (RTD)**
Monitor freezing in frozen food storage.
- ✓ **Infrared thermometers**
Measure surface temperature without contact.





So, let us study a little more about these types of sensors. First, we will talk about physical sensors. So, these sensors obviously measure physical parameters such as temperature, pressure, and humidity, and therefore, they play a crucial role in ensuring quality, safety, and efficiency in food processing. Like, for example, temperature sensors, there are thermocouples which are used for baking and roasting in the process line in the bakery. Temperature, that is, the resistance temperature detectors, known as RTDs they can be used to monitor freezing in frozen food during frozen storage, etc., or even Infrared thermocouples, which can measure the temperature without direct contact. So, these can be used to monitor and maintain conditions in various processes, including temperature. If you are online with your material and you want to study the surface temperature of the food

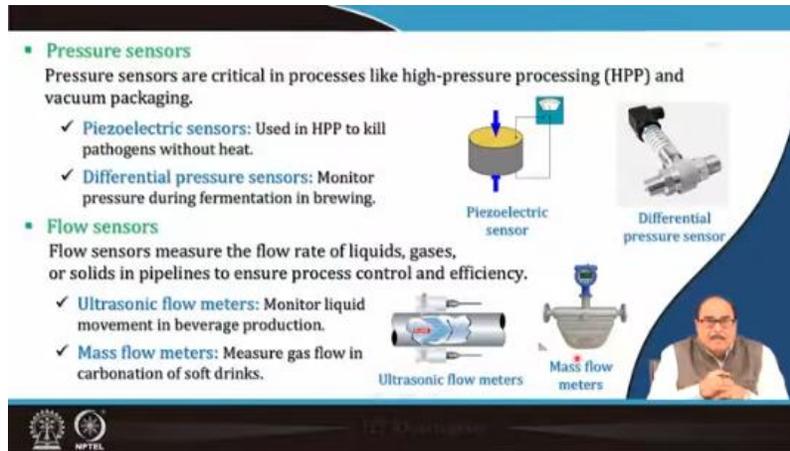
materials online, then infrared thermometers can be used or various. So, these are the different temperatures.

■ **Pressure sensors**
Pressure sensors are critical in processes like high-pressure processing (HPP) and vacuum packaging.

- ✓ **Piezoelectric sensors:** Used in HPP to kill pathogens without heat.
- ✓ **Differential pressure sensors:** Monitor pressure during fermentation in brewing.

■ **Flow sensors**
Flow sensors measure the flow rate of liquids, gases, or solids in pipelines to ensure process control and efficiency.

- ✓ **Ultrasonic flow meters:** Monitor liquid movement in beverage production.
- ✓ **Mass flow meters:** Measure gas flow in carbonation of soft drinks.



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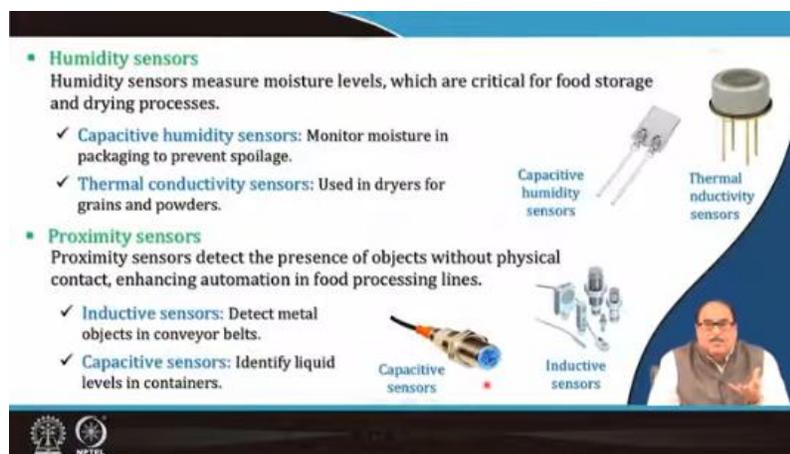
So, the pressure sensors are very, very important and critical for critical processes like high-pressure processing, vacuum packaging, etcetera. Piezoelectric sensors, you can see here, can be used in high HPP equipment. HPP is used to kill pathogens without the involvement of heat, and very high pressure is there. So, they can measure very high pressure and see that it is. Pressure is maintained inside the chamber or not. Similarly, differential pressure sensors like these can monitor pressure during fermentation or in the brewing process inside the fermentation chamber they can. Then, flow sensors measure the flow rate of liquids, gases, or solids in pipelines to ensure process control and efficiency. Ultrasonic flow meters monitor liquid movement in a beverage production line, mass flow meters can monitor gas flow in the carbonation of soft drinks, etc., and there are several other examples.

■ **Humidity sensors**
Humidity sensors measure moisture levels, which are critical for food storage and drying processes.

- ✓ **Capacitive humidity sensors:** Monitor moisture in packaging to prevent spoilage.
- ✓ **Thermal conductivity sensors:** Used in dryers for grains and powders.

■ **Proximity sensors**
Proximity sensors detect the presence of objects without physical contact, enhancing automation in food processing lines.

- ✓ **Inductive sensors:** Detect metal objects in conveyor belts.
- ✓ **Capacitive sensors:** Identify liquid levels in containers.



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Then, humidity sensors measure moisture levels, which is a critical factor in food storage or, as you will add, in the drying process. That capability, humidity sensors monitor moisture in packaging to prevent spoilage. Thermal conductivity sensors for humidity are used in dryers for grains as well as in powder materials, etcetera. Then, proximity sensors detect the presence of objects without physical contact, enhancing automation in food processing lines. There are inductive sensors, that is, they detect metal objects on the conveyor belts. Then, capacitive sensors can be used to identify liquid levels in containers, etcetera.

■ **Optical sensors**
 Optical sensors measure properties like size, shape, and color of food products.
 ✓ **Spectroscopic sensors:** Analyze color consistency in beverages.
 ✓ **Laser-based sensors:** Measure the thickness of dough.

■ **Different physical sensors and their application in food industry**

Sensor type	Example	Application in food industry
✓ Temperature sensors	✓ Thermocouples, RTDs	✓ Baking, freezing, pasteurization.
✓ Pressure sensors	✓ Piezoelectric sensors	✓ HPP, Vacuum packaging.
✓ Flow sensors	✓ Ultrasonic flow meters	✓ Beverage production, carbonation.
✓ Humidity sensors	✓ Capacitive humidity sensors	✓ Grain drying, cold storage.
✓ Proximity sensors	✓ Inductive sensors	✓ Sorting, conveyor systems.
✓ Optical sensors	✓ Spectroscopic sensors	✓ Color analysis, defect detection.

There are optical sensors, like spectroscopic sensors, which can analyse colour consistency in beverages. Laser-based sensors are used to measure the thickness of dough. So, these optical sensors measure properties like size, shape, and colour of food products. So, overall, I will give you a summary of the different physical sensors and their applications in the food industry. For example, temperature sensors like thermocouples, RTDs, etc., can be used in operations like baking, freezing, and pasteurisation. Pressure sensors can be used in processes like high-pressure processing, vacuum packaging, humidity sensors, such as capacitive humidity sensors, etc. They can be used in grain drying, cold storage, optical sensors like spectroscopic sensors; they can be used for colour analysis, detecting defects, etc. Flow sensors like ultrasonic flow meters, etc., can be used for beverage production lines, in carbonation lines, and so on.

Then we talk about chemical sensors, which detect and quantify specific chemical properties such as pH, gas composition, and the presence of specific contaminants or nutrients in food materials, packaging materials, or systems. They play a vital role in ensuring food safety, quality, and compliance with regulatory standards. Many times, we

use chemical sensors for finding out various ingredients, even nutrients, and toxic components,

Chemical sensors

- Chemical sensors detect and quantify specific chemical properties such as pH, gas composition, and the presence of specific contaminants or nutrients.
- They play a vital role in ensuring food safety, quality, and compliance with regulatory standards.

pH sensors

pH sensors measure acidity or alkalinity of food products, which is critical for fermentation, flavor profiling, and spoilage prevention.

- ✓ **Glass electrode pH sensors:** Measure pH in dairy products like yogurt or cheese.
- ✓ **Ion-selective field effect transistor (ISFET) sensors:** Compact and robust sensors for beverage and juice pH monitoring.



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and all those in biochemicals, etc., and therefore, to regulate them. Like pH sensors, they measure the acidity or alkalinity of food products. This is critical for processes like fermentation, flavour profiling, spoilage prevention, and so on. There are gas electrode pH sensors which measure pH in dairy products like yoghurt, cheese, etc. Even ion-selective field-effect transistor sensors can be used. They are compact and robust sensors. They can be used for the beverage and juice industries for the monitoring of pH.

Gas sensors

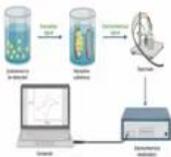
Gas sensors detect specific gases such as O_2 , CO_2 , and ethylene, which are crucial in storage and packaging.

- ✓ **O_2 sensors:** Ensure optimal oxygen levels in MAP.
- ✓ **CO_2 sensors:** Monitor CO_2 levels during carbonation.
- ✓ **Ethylene sensors:** Detect ethylene gas to control ripening of fruits and vegetables.

Electrochemical sensors

These sensors measure changes in electrical properties, often during chemical reactions.

- ✓ **Amperometric sensors:** Detect chemical spoilage markers like hydrogen sulfide in meat.
- ✓ **Conductometric sensors:** Measure ionic changes in water quality or salt concentration.



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Gas sensors like oxygen sensors, carbon dioxide sensors, ethylene sensors, etc. they can be used in active packaging, in intelligent packaging, modified atmosphere packaging to ensure the optimal levels of oxygen, carbon dioxide, or to detect ethylene gas to control the ripening process, etc. So, these gas sensors are very important in the packaging materials and permeability testing, as well as to find out the shelf life of the fruits,

vegetables and so on in the active packaging and other modified atmosphere packaging. Electrochemical sensors undergo major changes in their electrical properties. Often during chemical reactions, when there are in the foods, when you process, and when you store, various chemical interactions take place. These changes in the electrical properties because of these reactions can be measured using electrochemical sensors. Like amperometric sensor, they detect chemical spoilage markers like hydrogen sulphide in the meat. There are conductometric sensors that measure ionic changes in water quality or salt concentration, etcetera.

Enzyme-based sensors
 Enzyme-based sensors use biological recognition elements (enzymes) to detect specific compounds.

- ✓ Glucose sensors: Measure sugar levels in juices and syrups.
- ✓ Lactate sensors: Monitor lactic acid in fermented dairy and pickles.

Chemical spoilage detection sensors
 These sensors identify spoilage markers such as volatile organic compounds (VOCs) or amines.

- ✓ Ammonia sensors: Detect ammonia from protein breakdown in fish and meat.
- ✓ Volatile organic compound (VOC) sensors: Identify spoilage in packaged foods.

The diagram shows a flow from 'Analyze' to 'Amplifier' to 'Transducer', which produces a 'Measurable signal' and an 'Electric signal' that is sent to a 'Detector'. Below the diagram are images of an 'Ammonia sensor' and a 'VOC sensor'. A small video inset in the bottom right corner shows a man speaking.

Then, enzyme-based sensors use biological recognition enzymes or biological recognition elements like enzymes to detect specific compounds. There may be glucose sensors which measure sugar levels in fruit juices, beverages, or syrups, etcetera. Lactate sensors monitor lactic acid in fermented dairy products, pickles, and such other food materials. Then, chemical spoilage detection sensors, like those you know, detect when the food material is stored or when it is spoiled, as various gases or volatile components are released. Ammonia gas is one such component, particularly when meat products or fish products, etc., break down; the protein breakdown releases ammonia. So, there are ammonia sensors which can be used to detect the protein breakdown in such products. Then, the VOC sensor, that is, volatile organic compound detection sensors, can be used to identify spoilage in packaged food or amines, etc., can be used to detect spoilage in such products and so on.

Then, adulteration detection sensors like chemical sensors, which are also used to detect contaminants and adulterants in food products, such as a spectrophotometric sensor, detect melamine in milk, and chromatographic sensors identify pesticide residues in fruits and vegetables. So, again, to summarise, the different chemical sensors and their application in the food industry. You can say pH sensors, like glass electrode sensors, they can be used

- Adulteration detection sensors**
 Chemical sensors are also used to detect contaminants and adulterants in food products.
 - ✓ Spectrophotometric sensors: Detect melamine in milk.
 - ✓ Chromatographic sensors: Identify pesticide residues in fruits and vegetables.
- Different chemical sensors and their application in food industry**

Sensor type	Example	Application in food industry
✓ pH sensors	✓ Glass electrode sensors	✓ Monitoring fermentation, dairy processing.
✓ Gas sensors	✓ Oxygen, CO ₂ , ethylene sensors	✓ MAP, storage conditions, fruit ripening.
✓ Electrochemical sensors	✓ Amperometric sensors	✓ Spoilage detection, salt monitoring.
✓ Enzyme-based sensors	✓ Glucose, lactate sensors	✓ Sugar level monitoring, fermentation control.
✓ Spoilage detection sensors	✓ VOC, ammonia sensors	✓ Freshness evaluation, sea food and meat quality.
✓ Adulteration detection sensors	✓ Spectrophotometric sensors	✓ Melamine detection, pesticide residue analysis.

for monitoring fermentation process during dairy processing, fruit juice manufacturing, or beverage manufacturing, etc. Gas sensors like oxygen sensors, CO₂ sensors, and ethylene sensors can be used in modified atmosphere packaging, in maintaining the storage conditions, in shelf-life productions of various fruits in the fruit ripening process. Electrochemical sensors, which are the amphibious amperometric sensors, can be used for spoilage detection, salt monitoring, etc. Adulteration detection sensors, such as spectrophotometric sensors, can be used for melamine detection, pesticide review analysis, etc. Enzyme-based sensors, such as glucose sensors and lactate sensors, can be used for sugar level monitoring, fermentation control and various other purposes.

- Biological sensors**
 - Biological sensors, commonly known as biosensors, utilize biological recognition elements such as enzymes, antibodies, DNA, or cells to detect specific analytes.
 - These sensors convert biological interactions into measurable signals, enabling precise monitoring of food safety, quality, and authenticity.
- Enzyme-based biosensors**
 These biosensors employ enzymes as recognition elements to detect specific substrates in food.
 - ✓ Glucose biosensors: Detect sugar levels in juices and syrups.
 - ✓ Lactose biosensors: Measure lactose levels in milk and dairy products.

Now, let us talk about biological sensors. Biological sensors, commonly known as biosensors, utilise biological recognition elements such as enzymes, antibodies, DNA or cells to detect specific analyses or specific effects. These sensors convert biological interactions into measurable signals, enabling precise monitoring of food safety, quality,

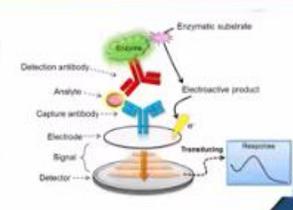
and authenticity. For example, enzyme-based sensors like glucose biosensors detect sugar levels in juices and syrups. Lactose biosensors measure lactose levels in milk and dairy products.

Pathogen detection biosensors
 Pathogen biosensors use antibodies, DNA probes, or aptamers to detect foodborne pathogens.

- ✓ **Immunosensors:** Can detect pathogens like *Salmonella* or *E. coli* in meat and poultry.
- ✓ **DNA-based sensors:** Can identify contamination by detecting pathogen-specific DNA sequences.

Allergen detection biosensors
 These biosensors are designed to detect allergens such as gluten, nuts, or milk proteins.

- ✓ **Antibody-based biosensors:** Can identify gluten in bakery products.
- ✓ **Aptamer-based sensors:** Can detect milk proteins in processed foods.








These biosensors employ enzymes as recognition elements to detect specific substrates in food. They use antibodies, DNA probes, or aptamers to detect foodborne pathogens like immunosensors, which can detect pathogens like *Salmonella* or *E. coli* in meat, poultry, or other food products. DNA-based sensors can identify contamination by detecting pathogens with specific DNA sequences. Allergen detection biosensors are designed to detect allergens such as gluten, nuts, or milk products, which contain various allergens. These sensors can detect allergens because each has specific characteristics, such as allergenic compounds, which can be identified. Antibody-based biosensors can identify gluten in bakery products, while aptamer-based biosensors can detect milk proteins in processed foods, and so on.

Toxin and contaminant detection biosensors
 These biosensors can detect harmful substances like mycotoxins, pesticides, and heavy metals.

- ✓ **Aflatoxin biosensors:** Can detect aflatoxins in grains and nuts.
- ✓ **Pesticide sensors:** Can monitor residue levels in fruits & vegetables.

Freshness and spoilage biosensors
 Freshness biosensors detect spoilage indicators such as volatile organic compounds, ammonia, or biogenic amines.

- ✓ **Amine sensors:** Can identify spoilage in fish and meat through biogenic amine levels.
- ✓ **Volatile organic compound (VOC) sensors:** Can detect gases released during food degradation.








Toxin and contaminant detection biosensors can detect harmful substances like mycotoxins, pesticide residues, heavy metals, etc., in food materials. Aflatoxin biosensors are now available, which can detect the presence of aflatoxin in grains, nuts, and other food products. Even pesticide sensors can detect or monitor the residue levels of pesticides in fruits, vegetables, or other such products. Then, freshness and spoilage biosensors detect spoilage indicators such as volatile organic compounds, ammonia, or biogenic amines. Then, amine sensors can identify spoilage in fish and meat through biogenic amine labels because, as I told you earlier, when these materials degrade, they result in ammonia reduction or amines, and these labels can indicate the level of spoilage of this product. So, these can be sensed by these amine sensors. Then, VOC sensors can detect gases released during food degradation, etc., and they can also be based on biological material.

• **Smart packaging biosensors**
 Integrated biosensors in smart packaging monitor food conditions during storage and transport.

- ✓ pH biosensors: Can detect pH changes in packaged meat and fish.
- ✓ Ethylene sensors: Can monitor ripening of fruits and vegetables.

• **Different biological sensors and their application in food industry**

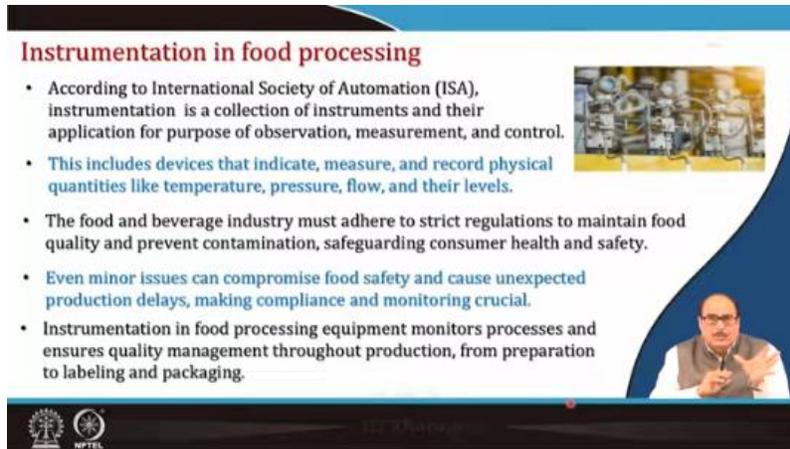
Sensor type	Example	Application in food industry
✓ Enzyme-based sensors	✓ Glucose, lactose biosensors	✓ Quality control in beverages and dairy products.
✓ Pathogen detection	✓ Immuno sensors	✓ Detecting <i>E. coli</i> , <i>Salmonella</i> in food products.
✓ Allergen detection	✓ Antibody, Aptamer sensors	✓ Gluten-free and allergen-free food labeling.
✓ Toxin detection	✓ Aflatoxin, pesticide sensors	✓ Monitoring grains, nuts, fruits, and vegetables.
✓ Freshness detection	✓ Amine, VOC sensors	✓ Evaluating spoilage in meat, fish, and sea food.
✓ Smart packaging biosensors	✓ pH, Ethylene sensors	✓ Real-time freshness monitoring during transport.





Smart packaging biosensors are integrated biosensors in the smart packaging that monitor the food condition during storage and transport. These sensors can tell what the condition of the food inside is, how the food is respiring, how the fruits are, what the shelf life is, all that the colour indicators can tell. And there are many times the temperature level indicates TTI levels, and all those are based on various sensors. Like pH biosensors can detect pH changes in packaged meat and fish, ethylene biosensors can monitor the ripening of fruits and vegetables. So, again, to summarise different types of biological sensors and their application, the food industry can say that enzyme-based sensors, such as glucose and lactose biosensors, can be used for quality control in beverage and dairy products. Allergen detections like antibody or aptamer-based sensors can be used to identify gluten-free products or allergen-free food labelling, etc., they can be used. Toxin detection sensors, such as aflatoxin or pesticide sensors they can be used for monitoring grain quality, nuts, fruits, vegetables, etc., online or during storage. Freshness detection sensors, such as amine

sensors or VOC sensors, can be used for evaluating spoilage in meat, fish, fruits, vegetables or other seafoods. Smart packaging biosensors, such as pH and ethylene biosensors, or TTI level indicators, freshness indicators, or moisture indicators, there are various sensors which can be used for real-time freshness monitoring during transport, packaging, and so on. So, these were briefly about the different types of sensors which are available or which can be used in food processing.



Instrumentation in food processing

- According to International Society of Automation (ISA), instrumentation is a collection of instruments and their application for purpose of observation, measurement, and control.
- This includes devices that indicate, measure, and record physical quantities like temperature, pressure, flow, and their levels.
- The food and beverage industry must adhere to strict regulations to maintain food quality and prevent contamination, safeguarding consumer health and safety.
- Even minor issues can compromise food safety and cause unexpected production delays, making compliance and monitoring crucial.
- Instrumentation in food processing equipment monitors processes and ensures quality management throughout production, from preparation to labeling and packaging.







Now, let us talk about instrumentation in food processing. So, according to the International Society of Automation, instrumentation is a collection of instruments and their application for the purpose of observation, measurement, and control. This includes devices that indicate, measure, and record physical quantities like temperature, pressure, flow, as well as maintain their levels; they also record and maintain these levels. The food and beverage industry must adhere to strict regulations to maintain food quality and prevent contamination, safeguarding consumer health and safety. And then, even minor issues can compromise food safety and cause unexpected production delays, making compliance and monitoring very critical or crucial. So, instruments and proper instrumentation in food processing monitor processes and ensure quality management throughout the production, from the preparation stage to levelling, packaging, and even in the supply chain by the time it reaches the consumers and is used. So, there are various instruments that can be used.

So, the major instrumentation systems used in food processing include traditional systems, modern systems, advanced systems, or emerging systems. That is, and as you can see here, this instrumentation input processing has transitioned from manual analogue controls to automated systems like PLC and SCADA-based systems for real-time monitoring.

Majorly used instrumentation system in the food processing

Instrumentation in food processing has transitioned from manual analog controls to automated systems like PLCs and SCADA for real-time monitoring, and now to advanced technologies like X-ray imaging and hyperspectral analysis for enhanced quality assessment and optimization.

The diagram shows a central box labeled 'Instrumentation' with four lines leading to boxes labeled 'Traditional system', 'Modern system', 'Advanced system', and 'Emerging system'. Below each box are several small icons representing the respective technology. A small inset video of a speaker is visible in the bottom right corner of the slide.

Now we have advanced technologies like X-ray imaging, hyperspectral analysis, enhanced quality assessment and optimisation, etc.

Traditional manual instrumentation systems

- In the early stages of food processing, instrumentation was primarily manual. Operators relied on analog devices to monitor and control processes.
- These were the basic tools in food processing which allowed operators to monitor and control various parameters through direct human intervention.
- These systems primarily utilized analog devices to measure critical factors such as temperature, pressure, and flow rates.

Examples

Temperature monitoring	Pressure measurement	Flow rate assessment
<ul style="list-style-type: none"> • Mercury-in-glass thermometers were commonly used to monitor cooking and storage temperatures. 	<ul style="list-style-type: none"> • Bourdon tube pressure gauges helped ensure that equipment operated within safe pressure limits. 	<ul style="list-style-type: none"> • Rotameters provided visual indications of fluid flow rates in processing lines.

The slide includes a small inset video of a speaker in the bottom right corner.

So, the traditional manual instrumentation and systems in the early stages of instrumentation were primarily manual. Operators relied on analogue devices to monitor and control processes. These were the basic tools in food processing, which allowed operators to monitor and control various parameters through direct human intervention. Systems like temperature monitoring, such as mercury-in-glass thermometers, were commonly used to monitor cooking processes or temperature during storage and during other processes, including pressure measurement. Bourdon tube pressure gauge helped ensure that the equipment operated within the safe pressure limit, etc. For flow rate assessment, rotameters were used; they provided visual indications of the fluid flow rates in processing lines. So, this system primarily utilised analogue devices to measure critical factors like temperature, pressure, flow rates, etc.

Traditional manual instrument systems (Contd...)

- **Analog measurement devices:** Instruments like mercury-in-glass thermometers, Bourdon tube pressure gauges, and rotameters provided real-time data through direct readings.
- **Manual data recording:** Operators manually logged measurements, often using paper records.
- **Direct process control:** Adjustments to processes were made manually based on the observed readings depending on the operator's expertise and judgment.

Challenges

- ✓ **Human error:** Manual readings and adjustments increased the potential for inaccuracies, leading to inconsistent product quality.
- ✓ **Labor-intensive operations:** Continuous monitoring and manual control required significant human resources, impacting efficiency.
- ✓ **Limited data analysis:** The absence of automated data collection hindered the ability to perform comprehensive analyses for process optimization.




So, like analogue measurement devices that we discussed, they were mercury-in-glass thermometers, Bourdon tube pressure meters, rotameters, all of which provided real-time data through direct readings. These systems' operators manually logged measurements, often using paper records, and adjustments to processes were made manually based on the observed readings, depending upon the operator's expertise and individual judgment. And, therefore, this posed certain challenges, particularly in modern food processing, that is, it involved human errors; manual readings and adjustments increased the potential for inaccuracies, leading to inconsistent product quality. It was a labour-intensive operation; continuous monitoring and manual control required significant human resources, impacting efficiency. Then, limited data analysis, that is, the absence of automated data collection, hindered the ability to perform comprehensive analysis for process optimisation.

❑ **Modern automated systems**

- Modern automated systems have revolutionized the food processing industry by enhancing efficiency, ensuring consistent product quality, and improving safety standards.
- These systems integrate advanced technologies to monitor, control, and optimize various stages of food production.

Key components

- PLC**
 - PLCs are digital computers used for automation of electromechanical processes.
- SCADA**
 - This offer comprehensive monitoring & control over processes by collecting data from various sensors & equipment.
- Robotics and automation**
 - Automated systems can handle repetitive tasks efficiently, leading to higher production rates.




So, these challenges led to the development of modern automated instrumentation systems, and particularly, modern systems have revolutionised the food processing industry by enhancing efficiency, ensuring consistent production quality, and improving safety standards. These systems integrate advanced technologies to monitor, control, and optimise various stages of food production, processing, and manufacturing. Key components in these advanced automated systems are PLCs, that is, programmable logic controllers. They are digital computers used for the automation of electromechanical processes. SCADA systems offer comprehensive monitoring and control over the processes by collecting data from various sensors and equipment. Robotics and automation, that is, automated systems, can handle repetitive tasks efficiently, leading to higher production rates. So, here is a pictorial presentation you can see, and if you go to any modern food processing or manufacturing industry.



So, you can find the system in place in various areas where they are used. PLC, SCADA, robotics, and automation are being used. They result in enhanced efficiency, improved quality control, increased safety, and, more importantly, they help in data-driven decision making and therefore result in greater perfection in the processing lines.

Advanced instrumentation systems

- The analysis of the quality of food like texture, micronutrient, macronutrient, freshness, etc. can be done rapidly using the advance non-destructive techniques.
- Advanced instrumentation systems, including X-ray imaging, hyperspectral imaging, magnetic resonance imaging (MRI), and micro-computed tomography (micro-CT) scans are the emerging techniques with immense scope for quality analysis non-destructively.

Non-destructive Rapid analysis Wide application Better efficiency

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Advanced instrumentation systems like these are non-destructive, rapid analysis methods which are widely used for better efficiency. These advanced instrumentation systems include x-ray imaging, hyperspectral imaging, magnetic resonance imaging (MRI), and microcomputed tomography (micro-CT) scans. These are, you can say, emerging techniques with immense scope for quality analysis in the food processing industry. As I told you, they are mostly non-destructive and provide online, real-time data very quickly.

X-ray imaging

- X-ray imaging is employed to detect foreign objects, assess internal structures, and verify fill levels in packaged foods.
- It identifies contaminants such as metal fragments, glass, and bone within products.

Hyperspectral imaging

- HSI captures a wide spectrum of light to analyze the chemical composition and quality attributes of food items.
- It assists in detecting defects, contamination, and assessing ripeness or freshness.

Magnetic resonance imaging

- MRI captures detailed internal images of food, assessing moisture, fat, and defects without damage.

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For example, X-ray imaging is used to detect foreign bodies, foreign objects, assess the internal structure of food materials, and verify fill levels in packaged foods. It identifies contaminants such as metal fragments, glass, and bones within the products. So, it can be used for various purposes. Hyperspectral imaging captures a wide spectrum of light to analyze the chemical composition and quality attributes of food items. It assists in detecting defects, contamination and assessing ripeness or freshness of the fruits, vegetables, then MRI imaging, magnetic resonance imaging captures detail internal images of food

assessing moisture, fat and even defects that it can be there without any damage they are nondestructive even whole fruit you can put into this take the image.

Then, micro-CT scanning offers high-resolution three-dimensional images of a food product, which allows for the analysis of internal microstructure, porosity, texture, structural integrity and so on. So, to summarise, you can say that if you want to detect a foreign object in the food material, you can go for x-ray imaging. This chemical composition can be found using HSI and MRI imaging technologies. Structural integrity of a food material can be found using X-ray imaging, MRI imaging and micro-CT scanning.

Micro-CT scans

Micro-CT scanning offers high-resolution, three-dimensional images of a food product's internal microstructure to carry out analysis of porosity, texture, and structural integrity.

Aspect	X-ray Imaging	HSI	MRI	Micro-CT
Foreign object detection	✓	✗	✗	✗
Chemical composition	✗	✓	✓	✗
Structural integrity	✓	✗	✓	✓
3D Visualization	✗	✗	✗	✓
Non-destructive testing	✓	✓	✓	✓

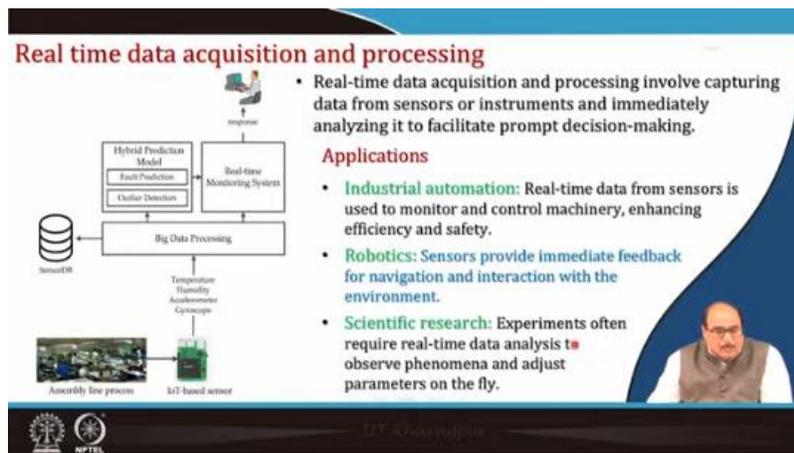
Even 3D visualisation of the object can be done using micro-CT imaging techniques, and non-destructive testing of the food materials can be done using all these emerging methodologies like X-ray imaging, HSI, MRI and micro-CT, etc., which are advanced systems.

Emerging system

- Industry 4.0 is revolutionizing the food processing sector by integrating advanced technologies such as the internet of things (IoT), artificial intelligence (AI), and robotics.
- These innovations bring automation, real-time monitoring, and data-driven decision-making to an industry for better efficiency, quality, and sustainability.

IoT enabled Food supply chain

Now, the emerging systems are what you know now, and we are now in the 5.0 era. Industry 4.0 or 5.0 is revolutionizing the food processing sector by integrating advanced technologies such as the Internet of Things, artificial intelligence, and robotics. These innovations bring automation, real-time monitoring, and data-driven decision-making to an industry for better efficiency, quality, and sustainability. We have discussed this in earlier classes. The Internet of Things in the application in the food industry, artificial intelligence and machine learning, its various components and how it works, and what its applications are in food processing, major applications, and robotics. So, we will take that up in a separate class on robotics because this is a very important aspect, and it is the future of the food processing industry, particularly if one wants to maintain precision and maintain the quality and safety of the food material, and to process and produce high-value food products.



So, this real-time data acquisition and processing, you know. This involves capturing data from sensors or instruments and immediately analyzing it to facilitate decision-making. Like here, for example, you have an assembly line process in the food processing online, there are various equipment and materials getting conveyed, and it is processed. So, you can have that, like IoT-based sensors, you can put into the system at various places in the earlier classes; we showed some examples of this. Then, this sensor senses the data, takes the data like sensors, maybe a temperature sensor, humidity sensor, accelerometer, gyroscope, and many other things. So, all these take the data and send it for big data processing across all these sensors. Whatever data they take is processed and put into the sensor database, which is the sensor database process, and then finally, it is used for that. Fault prediction model, fault prediction, outlier detection, etc., and finally gives a real-time monitoring system, and you get the response on the computer in no time, just really that,

like our senses take the data, send the signals to our brain, and it processes that data and gives its result output. Similarly, the same thing is done here: real-time acquisition and data processing. So, it can be used for industrial automation, like real-time data from sensors is used to monitor and control machinery, enhancing efficiency and safety. It can be robotics, like sensors, that provide immediate feedback for navigation and interaction with the environment, and proper management of the robot. decision-making by the robots, etc. Then, for scientific research, these experiments often require real-time data to develop models to optimise processing lines, etc. We conduct research, we conduct experiments, and then we collect the data and, on the basis of the data, we develop models sometimes, and we have our own predictions that yes, this So, all these things require real-time data acquisition and processing, which helps in scientific research to observe phenomena and adjust parameters, etcetera, online on the fly, and then to get proper results.

Summary

- Sensors and instrumentation play a pivotal role in modern food manufacturing, transforming how food is processed, monitored and controlled.
- Sensors are categorized as physical, chemical and biological depending upon their application.
- Instrumentation is vital for monitoring and controlling processes in the food industry for ensuring compliance with strict safety regulations and maintaining product quality from preparation to packaging.
- Industry 4.0 is transforming food processing with advanced technologies like IoT, AI and robotics, enhancing automation, efficiency, and quality.

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So, with this, I summarise this lecture by saying that sensors and instrumentation play a pivotal role in modern-day food manufacturing, transforming how food is processed, monitored, and controlled. Sensors can be categorised as physical, chemical, and biological sensors, depending on their application. Instrumentation is vital for monitoring and controlling processes in the food industry, ensuring compliance with strict safety regulations and maintaining product quality from preparation to packaging. Industry 4.0 is transforming food processing with advanced technologies like IoT, artificial intelligence, robotics, etc., enhancing automation, efficiency, and quality.

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These were the references used in preparing this lecture.



THANK YOU !



Thank you very much for your attention.