Tatiana Koutchma, Scientist, Agricuture and Agri-Food Canada.

Work Experience / History

2008 – present, AAFC, Guelph Food Research and Development Center

2000 – 2008, Illinois Institute of Technology, National Center for Food Safety and Technology, Research Associate Professor

Education

PhD – Moscow University of Food Production

PDF – McGill University, Montreal, Canada

Hobbies

Dogs, Photography, Gardening

Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

Canada

Validation of UV based technologies for foods and beverages

Tatiana Koutchma, PhD

Agriculture and Agri-Food Canada

Guelph Research and Development Center (GRDC)

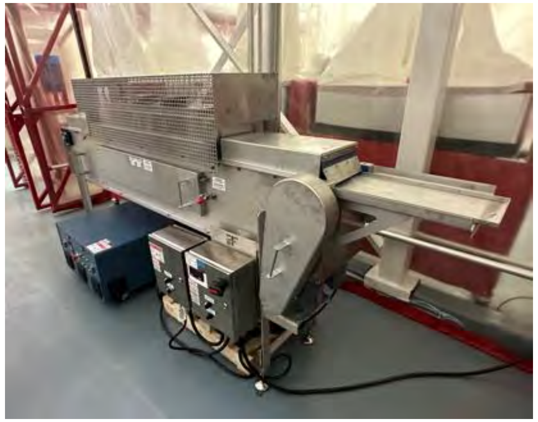
- Part of Agriculture and Agri-Food Canada's (AAFC), STB extensive network of research centres across the country that keep Canadian food among the best in the world.

- Scientists at the GRDC work with

  industry and other government partners to improve

  <u>food safety, sustainability, quality and nutrition</u>.

UV Program at GRDC/AAFC

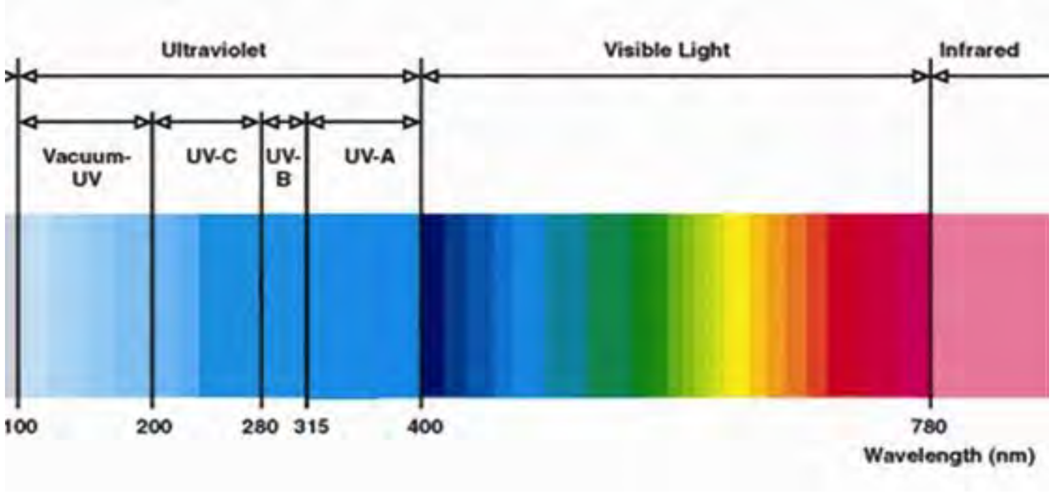


- UV sources
  low and medium pressure, excimer,
  pulsed and LEDs
- Drinks and beverages preservation and safety
- Validation of continuous UV systems for low UVT liquid foods and beverages
- Effects of UV on nutritional properties of cold pressed juices
- UV light to improve **toxicological** safety of apple products and grains
- UV light effects on generation of chemical compounds in foods (HMF)
- UV-C LEDs treatment of fresh produce

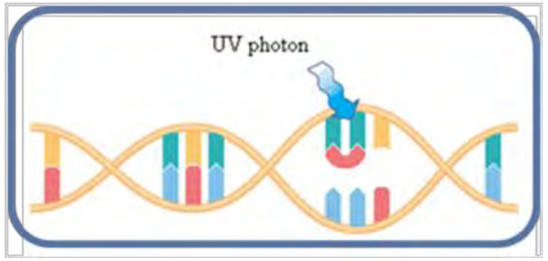
Content

- Review of the light based technologies for food applications
- Applications
  - Solid surfaces
  - Liquid products
- Regulatory approvals
- Principles of UV light process validation
- Critical UV process and product parameters
- Process scale up
- Challenges and Future needs

Basics of light processing



- Blue light – 400 – 450 nm – photodynamic inactivation
- UV-A – 315-400 nm
  - Oxidative damage to DNA, proteins, and lipids through ROS formation
- UV-B – 280-315 nm
  - Damages DNA via pyrimidine dimerization
  - Inactivates various repair enzymes via ROS formation
- UV-C – 180-280 nm – Highest germicidal efficacy
  - Damages DNA via pyrimidine dimerization



Conventional and Novel Sources of UV

- **Low pressure mercury (LPM) lamps**
  - Emit narrows bands at 184 and 254 nm
  - 254 nm light is approved for use with food
    - US FDA, Health Canada, EFSA

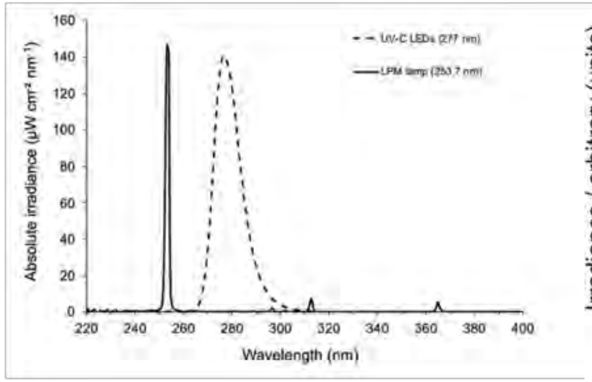
- **UV light emitting diodes (UV-LEDs)**
  - Can be made to emit a variety of wavelengths
    - UVA, UVB and UVC
  - Market for disinfection is growing

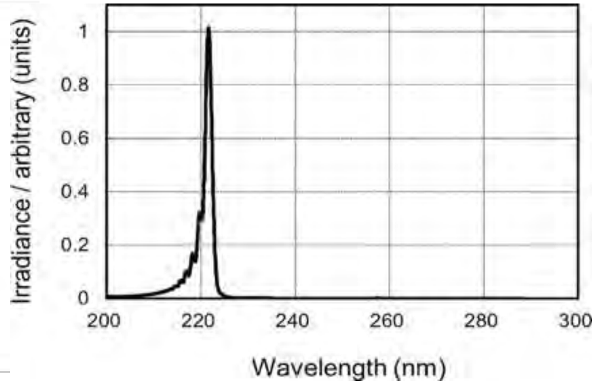
- **Excimer KrCl emitting at 222 nm – safe**

- **Medium pressure mercury lamps**
  - Emit many narrow bands ranging 200 – 600 nm
  - High power output
  - Mainly used for water disinfection
  - Sterilization of rinsing water (PMO)

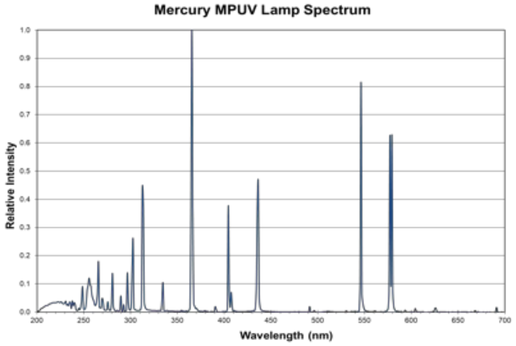
- **Pulsed Xenon and pulsed electronic UVC lamps**

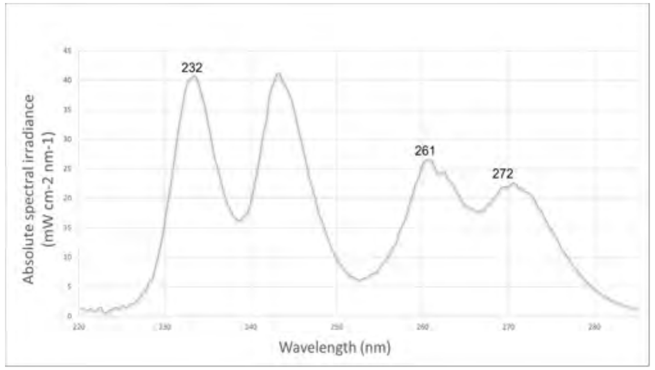
Monochromatic lamps and LEDs





Polychromatic lamps





Why Ultraviolet (UV) Light?

- **UV light is a novel, non-invasive food preservation technology**
    - Nonthermal
    - Nonionizing
    - Nonchemical
    - Organic
    - Low initial capital investment
    - Smaller space requirement
    - Lower operating costs
    - Energy efficient
    - Continuous

- **Effective against microbial hazards**
    - Food, water and air borne pathogens, spoilage organisms

Key milestones of UV light technology

- 1801 - discovered as light beyond violet “Chemical rays”
- 1892 - bactericidal action
- 1906 - silica quartz tube was developed
- since 1930 - well developed for **water** and **air** treatment
- 2001, 2005 – 253.7 nm approved by the US FDA and Health Canada for **juice** application
- 2012 - LEDs for **water**
- 2016 - UV light approved for **milk** by EFSA
- 2018 - Health Canada juice approvals and CFIA blood plasma
- 2022 - novel UV sources at 222 nm, pulsed light, etc

Legislative Status of UV

- **USA – UV irradiation is a food additive**

FDA: CFR 21 179.39 UV radiation for the processing and treatment of food

  - Surface of food and food products
  - Potable water
  - Juice products

    Reduction of human pathogens and other microorganisms

    Turbulent flow at Re >2000

  - Baking yeasts
  - Mushrooms
  - Milk

  The acceptance of UV as a food additive for dairy applications 21 CFR 179.39

  PMO submission

- **Canada – UV light is a novel technology – Novel Foods**

HC: Approval by Novel Foods Regulations

  - Apple Cider, shelf-life extension

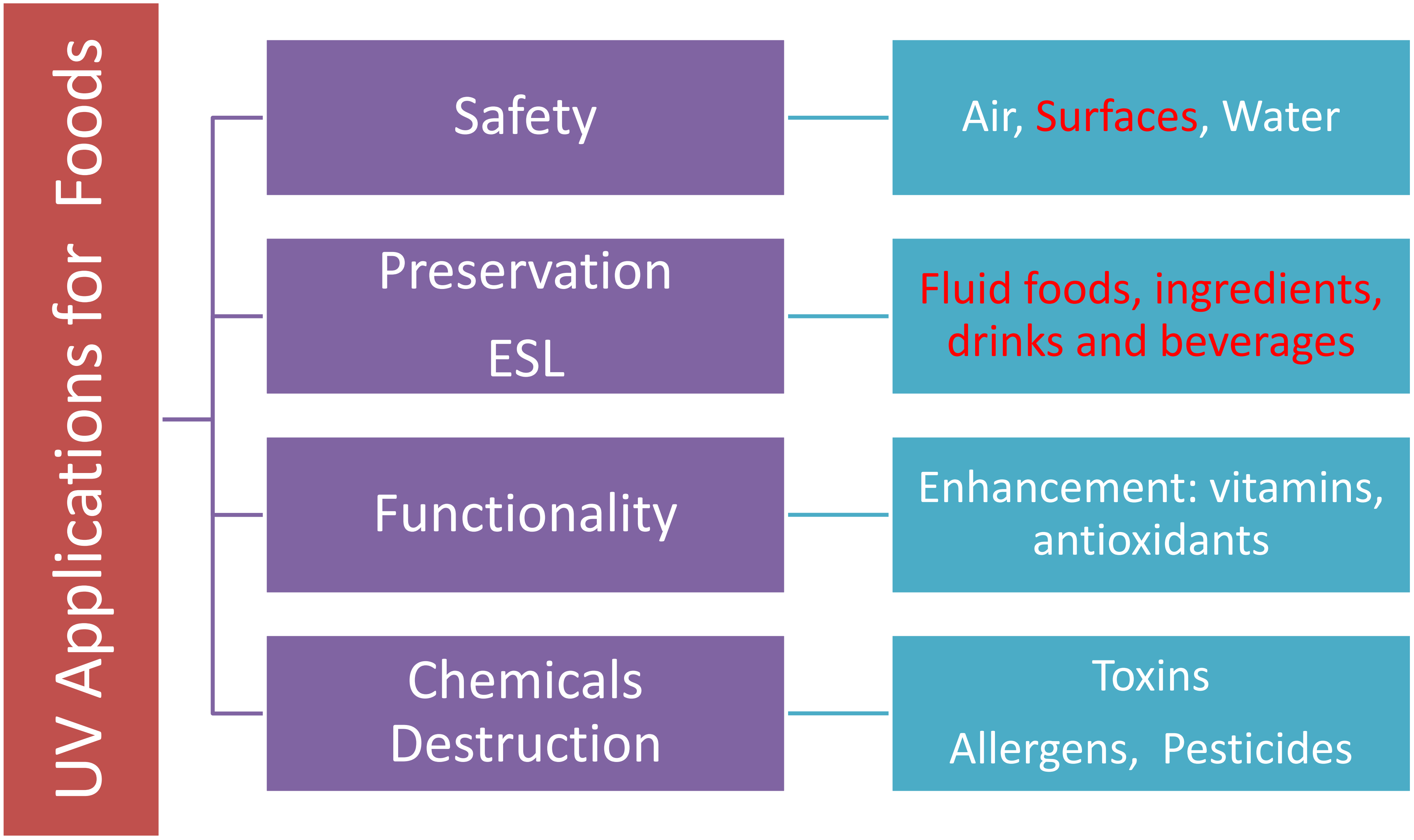
- **EU**

EFSA: Approval by Novel Foods Regulations

  - Milk after pasteurization for shelf-life extension, bread

- **NZ and Australia**

FSANZ: Demonstrate equivalence to thermal treatment


UV Applications for Foods
Safety
Air, Surfaces, Water
Preservation
ESL
Fluid foods, ingredients, drinks and beverages
Functionality
Enhancement: vitamins, antioxidants
Chemicals Destruction
Toxins
Allergens, Pesticides

1. UV Safety Applications at Food Facilities

APPLICATIONS

- Air and water treatments
- Non-food contact surfaces
  - Walls, ceilings, floors
- Food contact surfaces
  - Conveyor belts
  - Packaging
  - Equipment
- Food surfaces
  - Pre-packaging
  - Post-packaging

Figure 1. Contamination sources that compromise sanitary conditions may come from a variety of areas in the food processing and supply chain.

UV-PROTECTION AGAINST

- **Airborne**
- Molds Spores, human pathogens, viruses
- Recently COVID-19 outbreaks at meat plants
- **Waterborne**
- Viruses and Bacteria spores
- **Foodborne**
- Bacteria, spores
- **Spoilage**
- Yeast, molds, lactobacilli

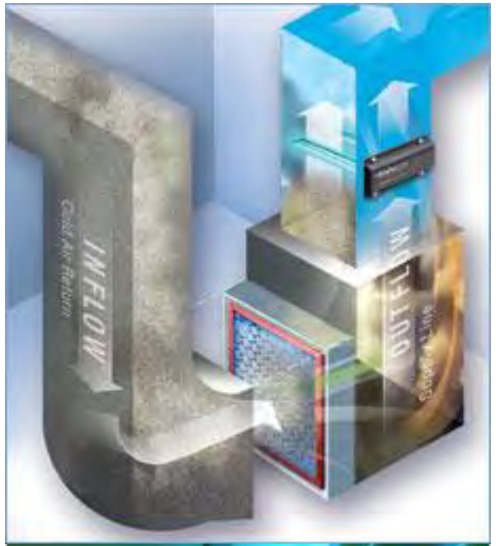
UVC for Air Quality Control

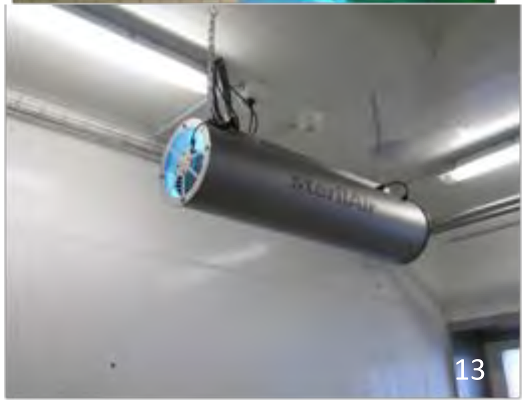
Long established, air quality has a direct effect on the final product.

Recently, air quality has been shown to have direct effect on workers!

UVC quality measures can be applied in the following locations:

- Incoming Air (ducts disinfection)
- Air circulation/ventilation
- Air recirculation within processing area
- Air treatment close to worker locations to prevent transmission
- Air to product packaging
- Air to product transport
- Air to wet air process control
- Air to positive pressure directional flow





Food Contact Surface

- USA FDA definition of a "Food-contact surface” for regulatory oversight:
  (1) A surface of equipment or a utensil with which food normally comes into contact; or
  (2) A surface of equipment or a utensil from which food may drain, drip, or splash:
  (a) Into a food, or (b) Onto a surface normally in contact with food
- Packaging
  - films
  - caps
  - cups, tubes
- Conveyors
- Equipment surfaces
- Utensils
- Materials
  - ceramic, wood, rubber, glass, stainless steel, plastic

WASH, RINSE and SANITIZE other food contact surfaces.

Food Product Surfaces

- **Ingredients**
  - Food powders, peppers and wheat flour
  - Grain, seeds
- **Raw products**
  - *Listeria* and *Salmonella* on fresh meats, poultry, fish and RTE products
  - Salmonella in Shell-eggs
  - Fresh Produce
- **Finished products**
  - Bakery
  - Packaged RTE products






UV process design and validation

- The required Dose (UV req) in mJ/cm^2 is needed to achieve the target logarithmic inactivation or specific logarithmic reduction (SLR) on the surface of material for the target pathogen

$$UV\ req = SLR\ x\ D_{uv} - value$$

- Validation of UV applied dose

$$[UV]\ (dose\ applied) = I\ (uv).t$$

$$UV_{dose\ applied} > UV_{req}$$

- Evaluation of UV exposure uniformity on tested surface

- Effect of critical process parameters
  - Temperature, distance from the source, conveyor speed

US FDA 21 CFR Part 179.39

US FDA is only limiting the level of intensity on the surface

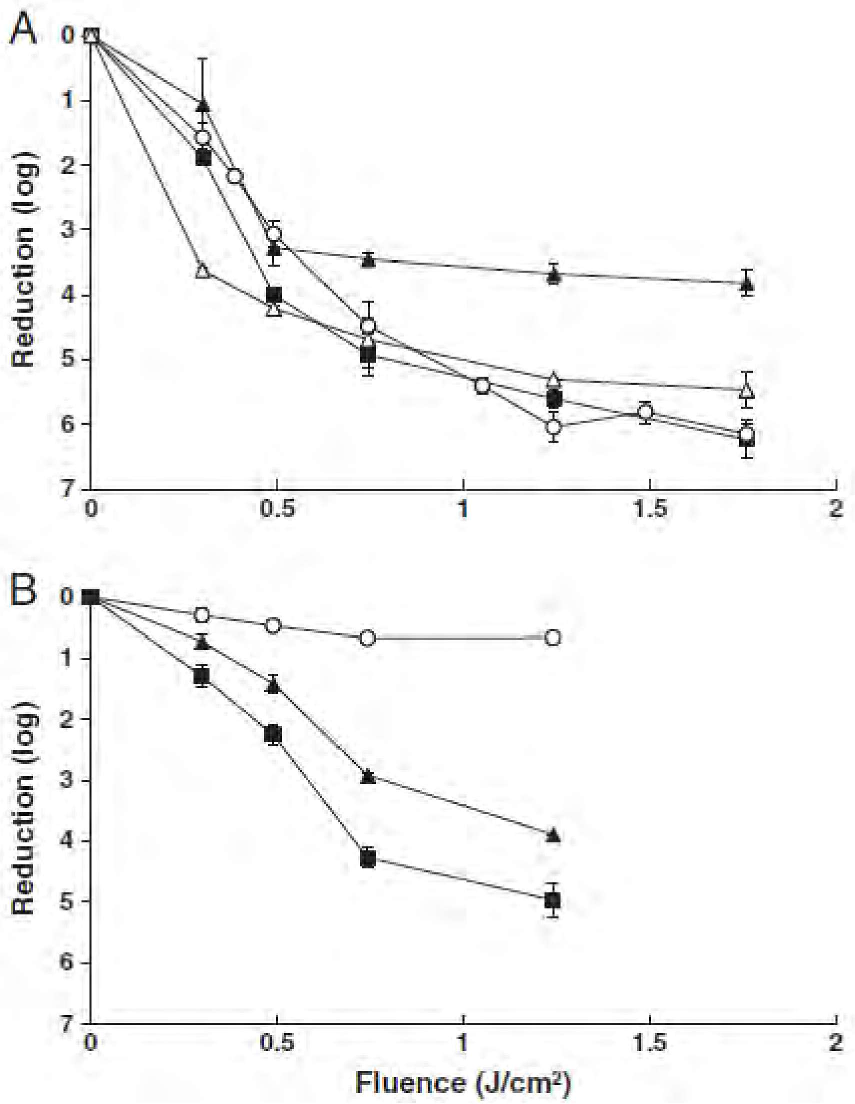
1 W (of 2,537 A. radiation) per 5 to 10 ft^2

OR **216 micro W/cm^2 -** maximum intensity (I_{uv}) on the surface

UV Dose – [microW X Seconds /per unit of area] or **microJ/unit area**

UV applied = I_{uv} x time = 216 mW/cm^2 x 100 s = 21600mJ/cm^2

Microbial reduction under UV surface treatments



Challenges : non-linear inactivation, tailing

- Surface characteristics
  - Roughness, dry or wet, optics
- Materials
- Food composition
- Biofilms
- Duration of the treatment
- Tailing effects
- Effects on quality parameters

Solutions

- Continuous UV vs PL light
- Excimer Lamps in Far UV range with higher energy of photons (222 nm)
- Combination of LEDs at 254-280 nm
- Advanced oxidation
  - UV + H_2O_2, O_3, TiO_2

UV sensitivity of microorganisms D_{10} – value

- Type of organisms
- Wavelength
- Properties of the medium
  - Dry or wet
  - food /composition
  - Nature of contact surface
- Action spectra
- 253.7 nm is not the most effective wavelength

Air	Water	Food
Viruses	Cryptosporidium	Parasites
Bacteria	Bacteria Yeasts	Bacteria Yeasts
Spores	Spores	Spores
	Viruses (Adenovirus)	Viruses
		Molds spores
RH, T°C	Turbidity	pH, Aw composition

UV Resistance (D-value) on the Surfaces

Type of organisms

Moulds spores > Viruses > Spores > Bacteria > Yeasts

Nature of surfaces, its roughness, light reflection

Smooth surfaces

D_{10UV} varies from 2.5 up to 3.5 mJ/cm^2

For product surfaces

D_{10UV} of *L. monocytogenes* can be higher by 2 or 3 orders of magnitude of 200-300 mJ/cm^2

Wavelength

Biodosimetry Studies

Goals

- To determine the most UV resistant organism
- To measure the D_{10} - dose of the most resistant organism
- To select Indicator/surrogate organism for the pilot scale or commercial validation
- To establish the required design UV dose
- To determine surface effects on efficiency of UV inactivation

Principle

- Bench top scale collimated beam units
  - Measurable UV irradiance on the surface
  - UV irradiance can be adjusted
- Commercial wavelength
- Conduct dose-response studies for challenge organisms on the product surface

Log (N/No) vs UV dose

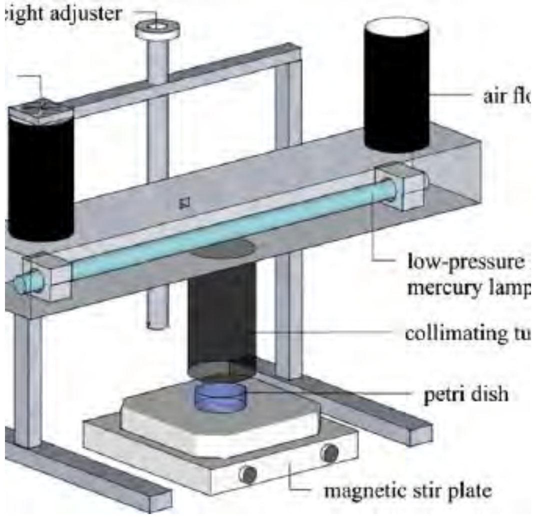
- If the dose-response data are linear – D_{10} dose is calculated

$$D_{10} = 2.3/k,$$

k – inactivation rate constant, cm^2/mJ

Bench top units: continuous UV

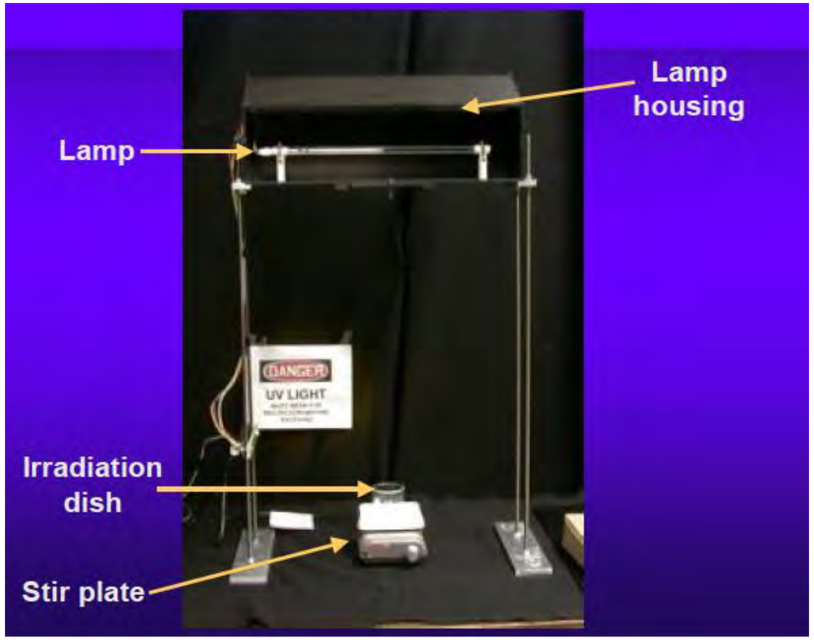
Collimated UV light



Collimated LEDs unit, AquiSense

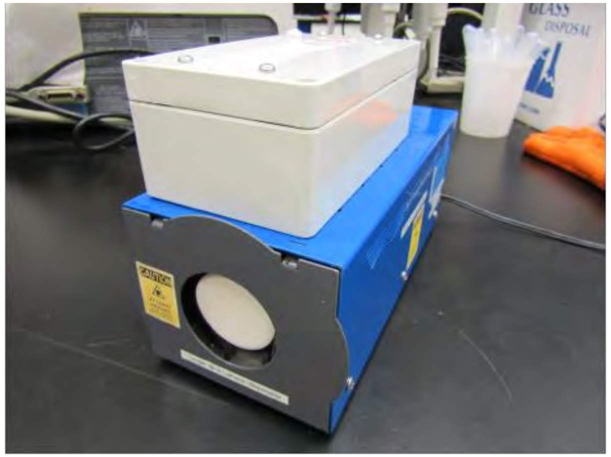
Pulsed UV and Light Bench Units

Pulsed UV



Pulsed Light

Pulsed electronic UV



Scale Up To Commercial System

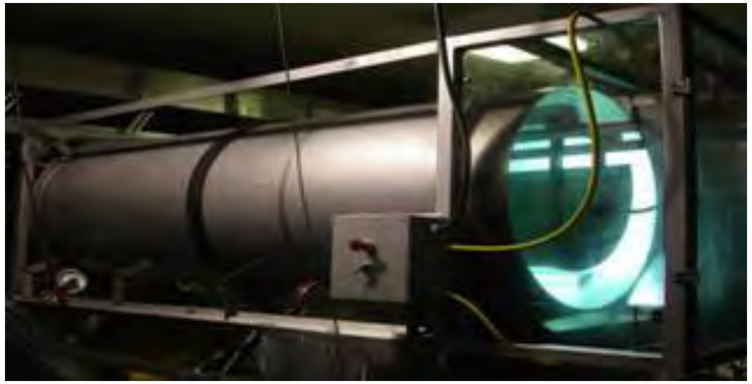
Challenge

- To deliver the design UV dose to the product surface uniformly in commercial scale

Validation objective

- To achieve required microbial log reduction of the indicator organism consistently in time in the pilot or commercial operation

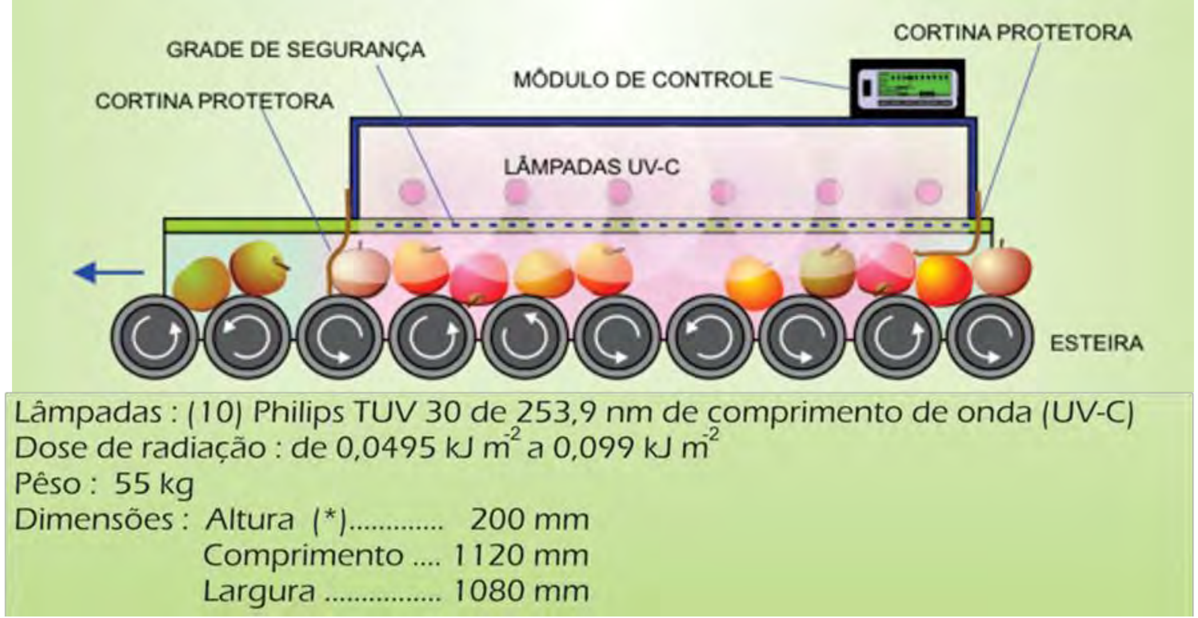
UV systems for Food Surfaces



UVC Tumbling Machine,
Reyco Systems, USA

Blue Light Module,
Heraeus Noblelight, GmbH

Conveyor belt UV system
SterilAir Switzerland



Critical Parameters For Microbial Validation

Process

- UV intensity on the surface
  - UV lamp output
  - Number of lamps
  - Lamp life time
- Distance between lamp and surface
- Exposure time

Product

- Surface or packaging characteristics
- Geometry, shape
- UV light reflectance, shadowing
- UV resistance of organism of concern
- Surrogate or indicator organism
- Inoculation and recovering methods

Control Parameters

Process

- Measurement of UV intensity
  - Maximum and minimum levels
- Treatment time/Exposure time
- Uniformity of UV irradiance
- Lamps performance/age
- Heating
- Cleaning

Product

- Variability
- Surface exposure
- 

Foods surfaces

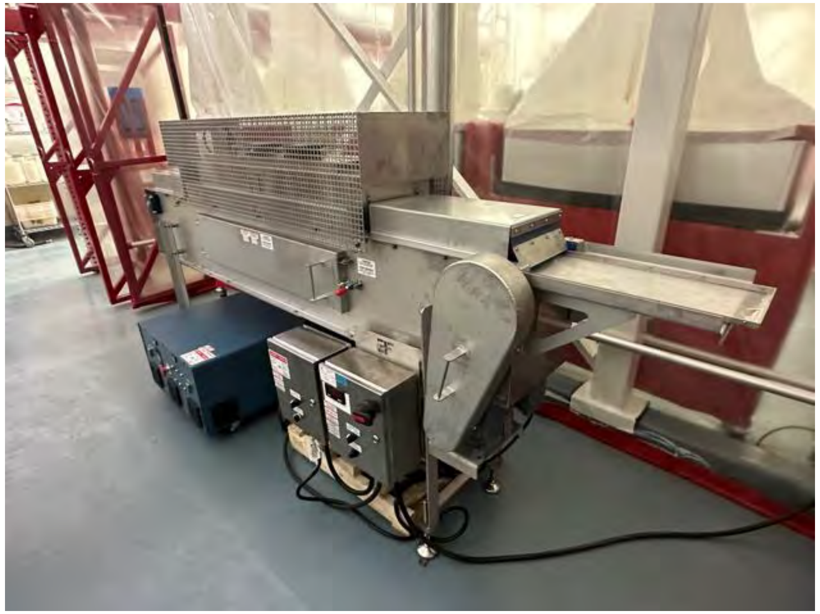
- Fresh, processed or frozen foods
- Packaged foods
  - Some plastic materials are UVC transparent

Goal

- Safety and shelf-life extension
- Natural micro flora is more UV resistant than food pathogens.
- Maximum reduction can be 2 or 2.5 logs because of the surface properties.
- The **minimum** UV dose of 1000 mJ/cm^2 delivered **in a short time to provide production rate.**
- The lamps that can be used are 253.7 nm amalgam or mercury lamps.
- For poultry and pizza the UV system and doses can be different

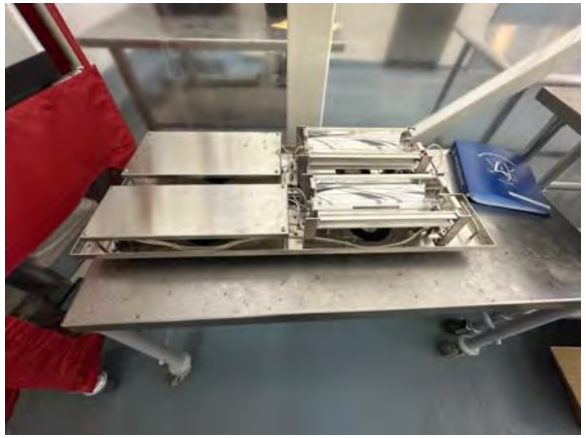
- Depending on a target product UV dose estimate can be provided and should be adjusted
- The effect of UV light on food attributes (quality, sensory, composition) have to be evaluated
- Regulatory approval will be needed in Canada (Novel Foods) and USA (FDA, USDA)

UV food processing conveyor



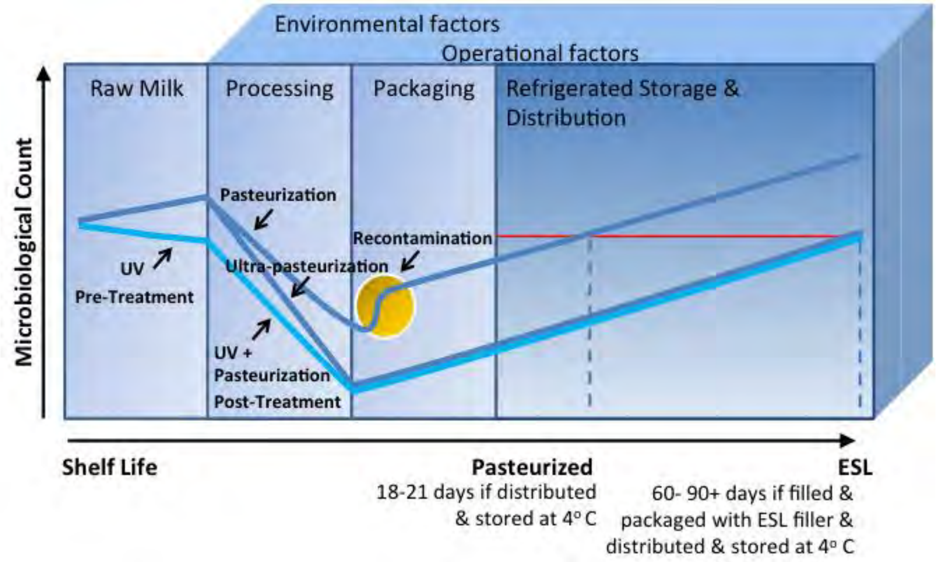
Interchangeable UV lamps and LEDs sources

- Low pressure lamp at 253.7 nm
- Medium pressure
- Pulsed electronic lamp
- UVC LEDs at 277nm

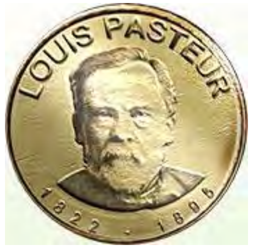


2. UV Preservation Processes for Liquids

- Shelf-life extension of raw products
  - Milk
  - Juice products (cold pressed)
  - Liquid eggs
- Alternative to Heat Pasteurization
  - Fruit and vegetable Juices (high acid or acid)
  - Milk
  - Coconut water, coconut juice (low acid)
- Adjunct to Heat Pasteurization
  - Milk
  - Liquid Eggs
  - Low Acid drinks (coffee)



Challenge organisms are different for each process and its intended effect!



Pasteurization Concept

- Eliminate the risk of most pathogenic bacteria:
  - *E.coli, Salmonella, Listeria*
- Applied for liquid foods
- Milk, beer, juices
- Requires refrigerated storage

- Solids foods can be pasteurized in consumer packages to eliminate post-processing contaminants

UV as Alternative to Pasteurization

- Juices
  - high acid and acid pH < 4.5
  - Pathogenic *E.coli, Listeria monocytogenes, Salmonella, Cryptosporidium parvum*
- Ingredients
  - Water in dairy processing
  - Liquid eggs (against *Salmonella*)
- Beer

UV Pasteurization of Juices

Validate against

Natural micro-flora,

Enzymes

Shelf-life studies

Validate for pertinent organisms

pH > 4.6 – low acid category

Clostridium botulinum

pH <3.5 – high acid category,

pH<4.6 acidic

Pathogenic E.coli, Listeria monocytogenes, Salmonella, Cryptosporidium parvum

Establish

Specific Log Reduction

Design Reduction Equivalent Dose (RED)

Critical process and product parameters

Quality effects

Nutritional effects

vitamins, polyphenols, anti-oxidants

Sensory studies

UV as Adjunct to Pasteurization

- Spores are organism of concern
  - Low Acid juices and beverages
    - Carrot juice, coconut water, iced coffee
    - *C. botullinum*
    - Combination with mild heat can be required

- Extended shelf-life products
  - Raw milk or juices
  - Acid juices
    - Alicyclobacillus can survive pasteurization
    - juices, iced teas
  - ESL milk
    - Heat resistant spoilage spores
    - UV is used as a post pasteurization treatment

Validation Objectives

Lab and Pilot Scale

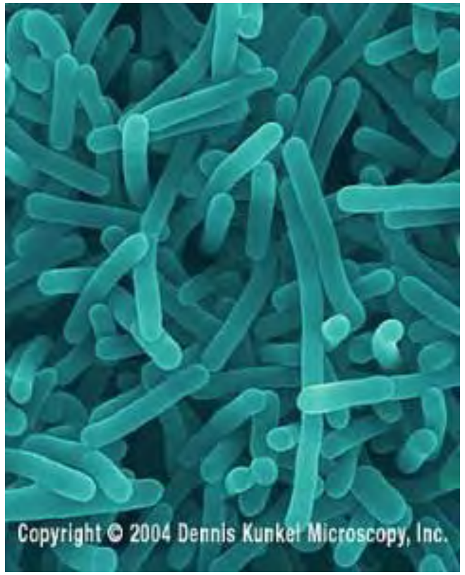
- To determine the most UV resistant pathogen of concern for specific product
- To determine the surrogate organism
- To establish Design Reduction Equivalent Dose (RED)
- To establish critical process and product parameters
- To achieve the specific microbial log reduction of the indicator organism consistently in time in the pilot scale operation

Commercial Operation

- Installation qualification
- To establish and verify operational RED
- To test maximum and minimum process and product parameters
- Reporting and commissioning

Pertinent Pathogen(s) Selection

- Specific for juice, based on previous outbreaks
- Difficult for juices with no outbreaks
- Most resistant pathogen to treatment
  - If no literature available, preliminary work required.
- May be more than one pertinent pathogen

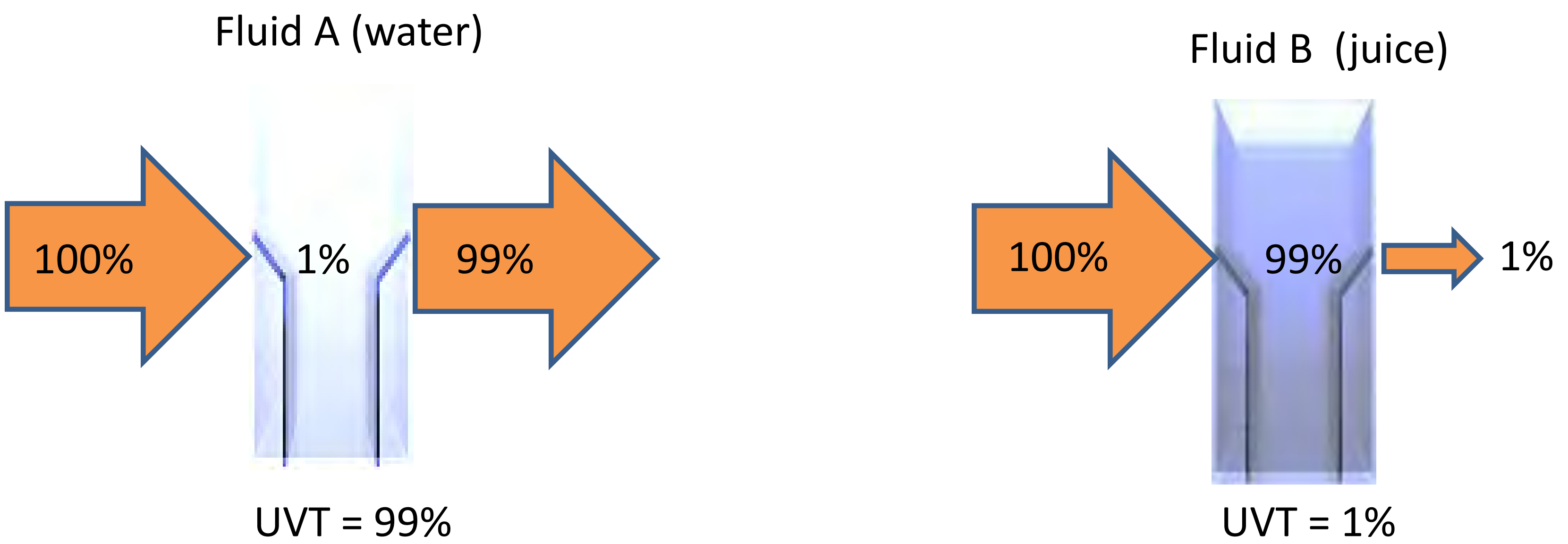


Surrogate Microorganism

- Non-pathogenic strain,
  phylogenetically close to pathogen of concern
- Capable of coexisting with the pathogen
  in food matrix
- Least affected by the nature of food product (pH)
- The processing resistance of the surrogate organism should be equal to or greater than that of the most resistant pathogenic strain

What is UV transmittance?

- UVT= % of light transmitted through 1cm
- $I(x) = I_0 10^{-x/UVT}$ ~Beer's Law. Exponential.
- $I_{avg} = \frac{1-10^{-l/UVT}}{l/UVT \ln(10)}$ = <u>average</u> intensity

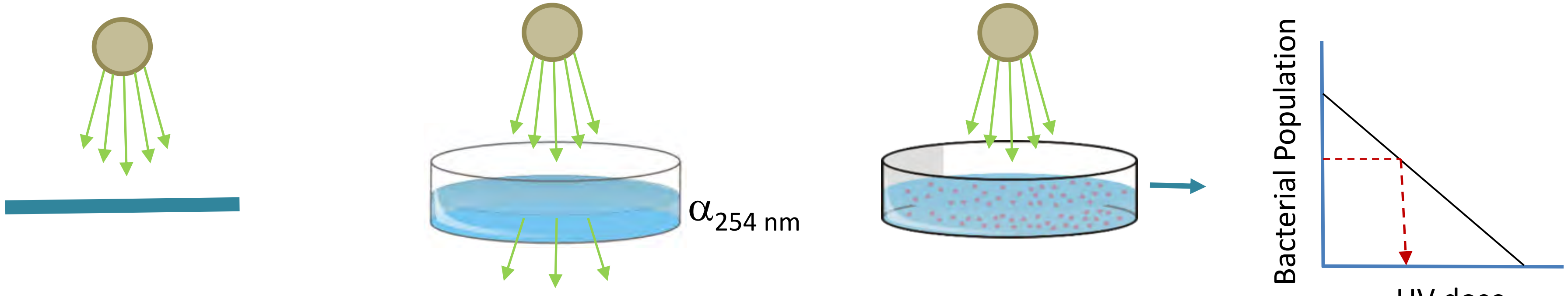


UV Dose

- **Delivered light energy is termed the UV fluence or dose:**

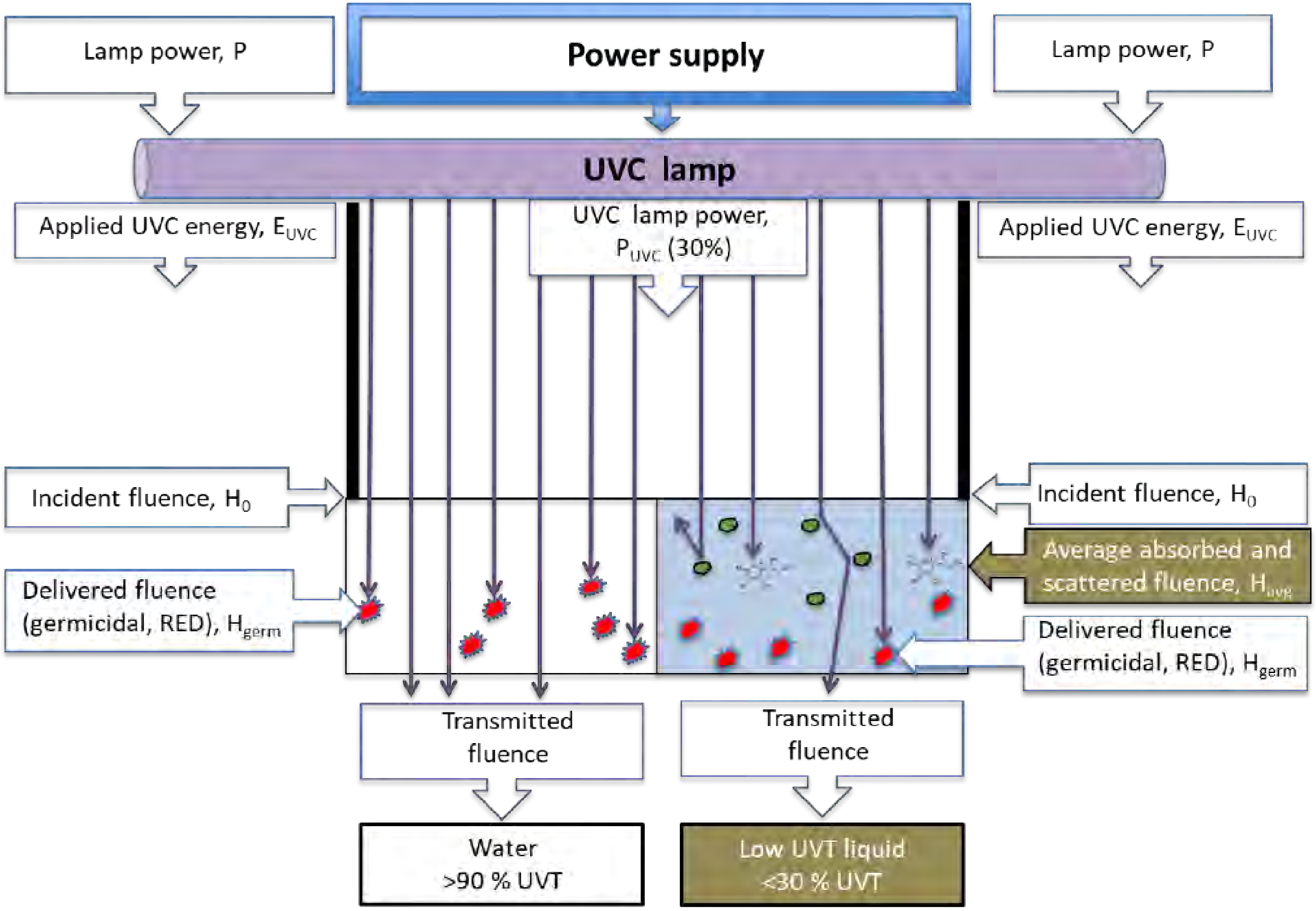
UV dose (mJ cm^{-2}) = Irradiance (mW cm^{-2}) x Exposure time (s)

UV dose measurements are calculated depending on treatment conditions:



Incident UV dose | Absorbed UV dose | Reduction equivalent UV dose

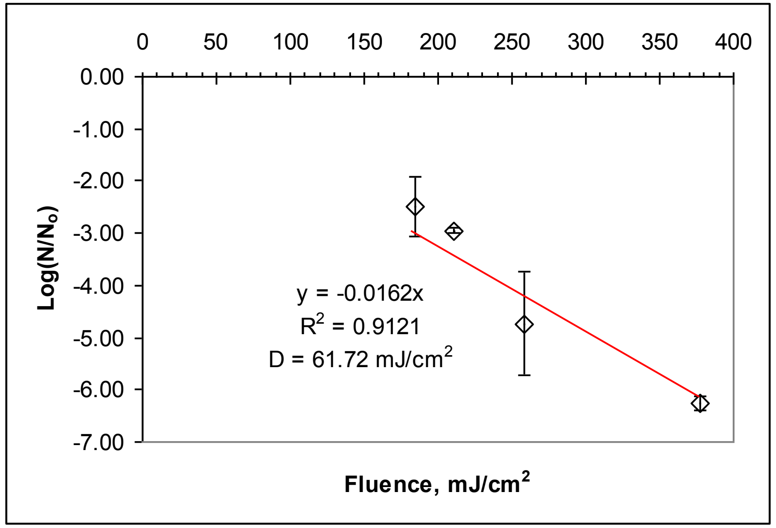
UV energy, fluence and dose



UV process design - Biodosimetry

1. Bench-top kinetic study

B. subtilis spores



2. Pilot scale microbial challenge study

In multiple lamp UV unit

UV dose = D_{10} x Log (N/No)

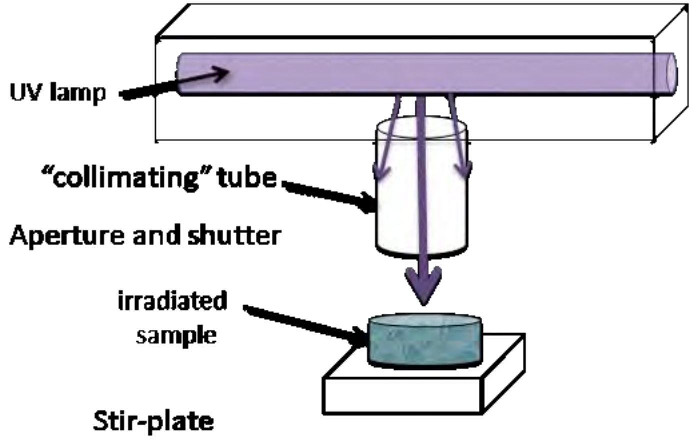
Design UV dose to be delivered in the process

Log (N/No)

Specific Log reduction

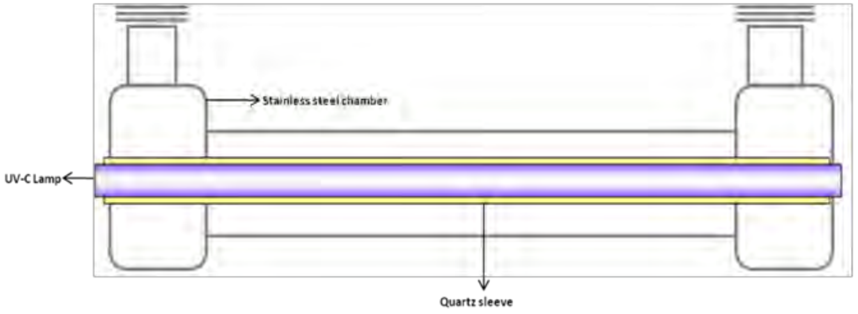
Performance objective

UV units for bio-dosimetry



Collimated beam unit

Continuous static mixers "Vivatec" with known parameters



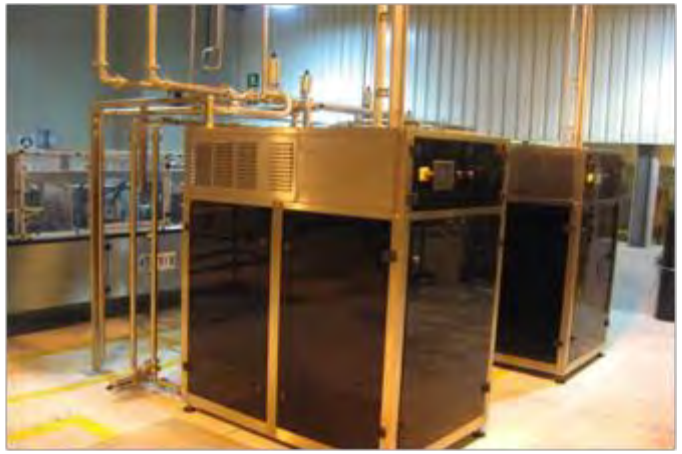
Designed lab scale unit with similar flow and irradiation parameters to commercial unit

Commercial UV equipment validation

- Each piece of UV unit must be validated in order to legally operate within the facility.
- The goal is to produce consistent results with minimal variation without compromising the integrity of the product and the persons operating the equipment.
- A plan of validation should be drafted and executed by engineers in order to satisfy guidelines.
- Operational UV dose is established based on the results of the equipment validation testing

Examples of Turbulent Flow UV systems

Mikrotec, UK



Surepure Inc, SA

Industrial UV Processing of Fresh Juice

- Juice processors still need to determine operational UV dose for each product:

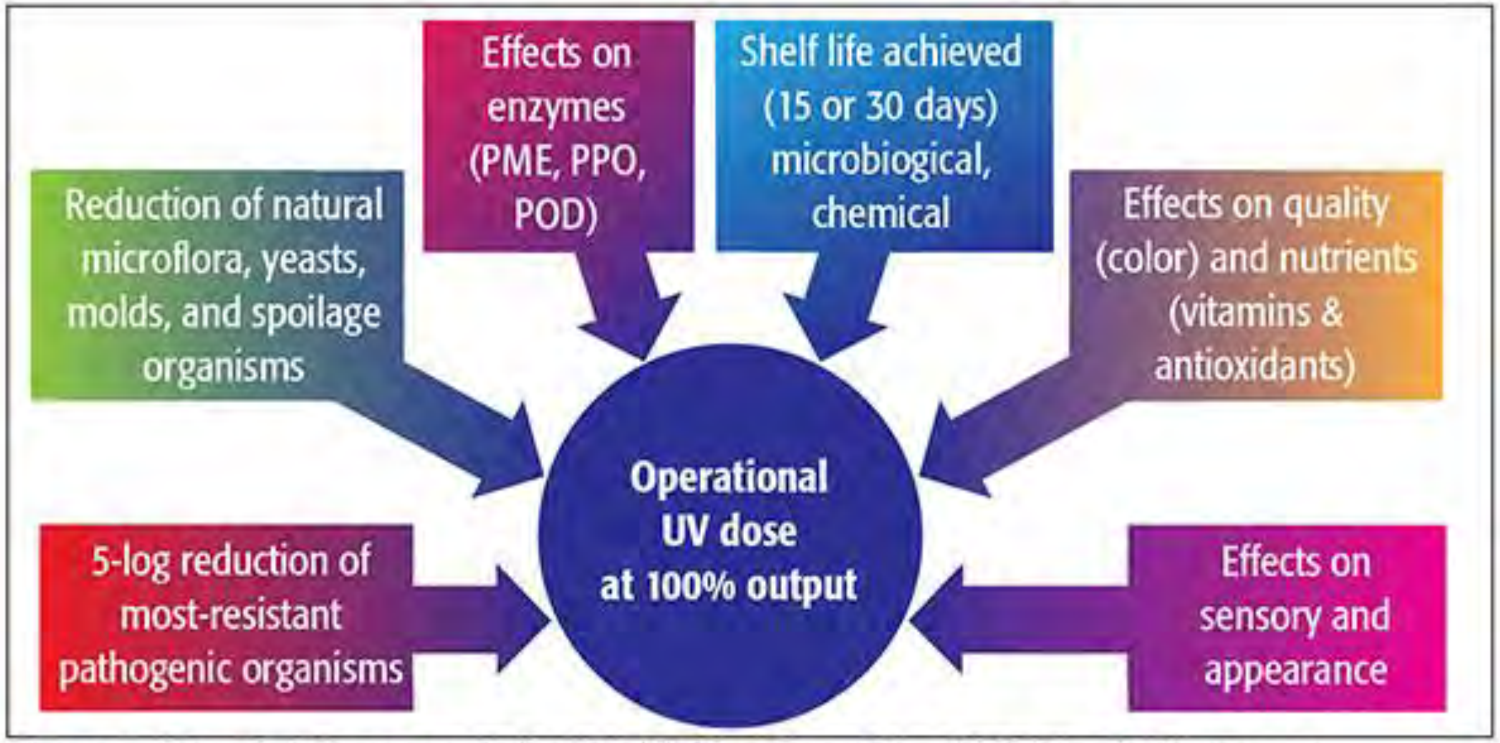
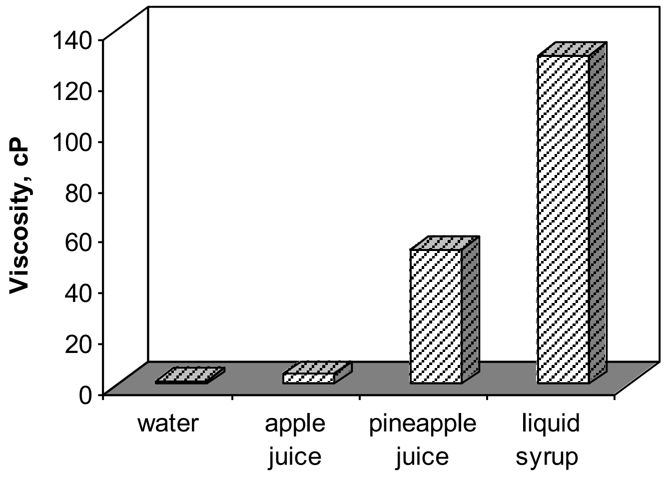


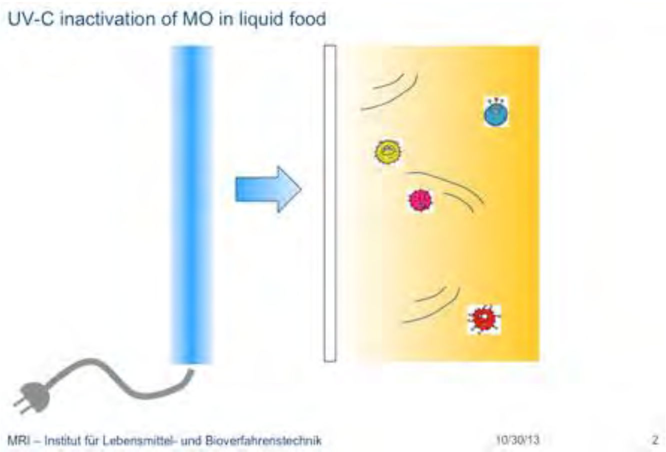
Figure 1. Essential Components for Establishing Operational UV Dose in Beverages

Critical Parameters

- **Product**
  - pH, water activity, composition
  - Viscosity
  - UVT /turbidity/particle size



- **Process**
  - Flow
    - rate/pattern
    - Mixing efficiency
    - Residence vs Exposure time
  - Light source type/ intensity/sleeves/age
  - UV dose
    - Applied Energy
    - Incident Fluence
    - Absorbed Fluence
    - Delivered Dose



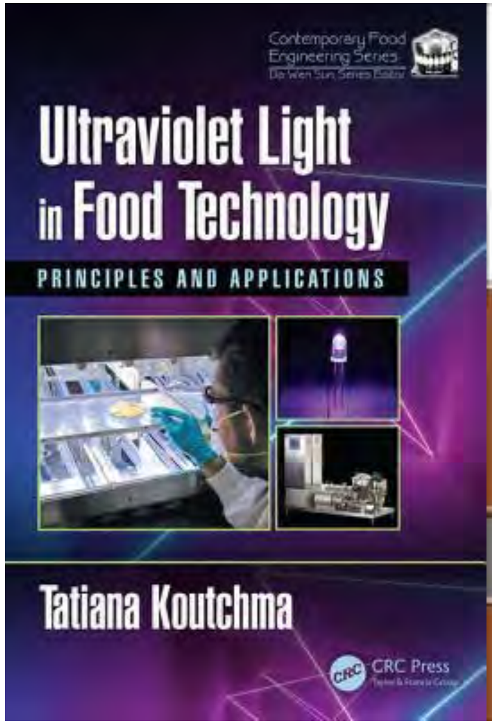
Scale Up Activities

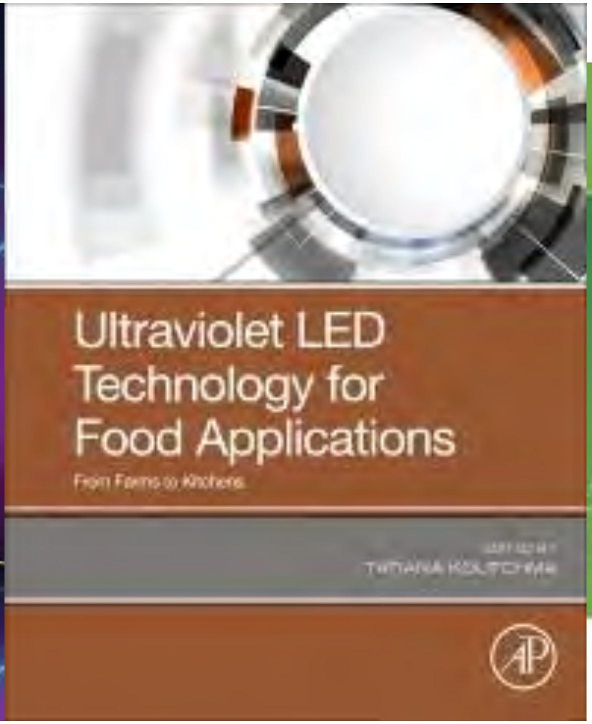
Activity	Lab scale	Pilot scale	Commercial
UV unit	Collimated beam	Pilot Prototype	Commercial unit
Organisms	Pathogen	Surrogate	Surrogate
Dose	Design RED	RED	Operational RED
Critical process parameters Flow rate Intensity	Yes No	Yes Minimum & Maximum	Continuous monitoring Calibration Verification
Quality validation		Yes	Yes

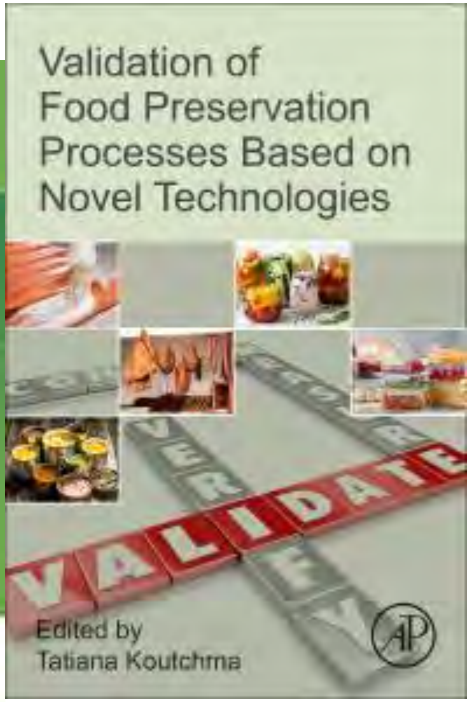
Summary

- Application of light based technologies in food industry is growing in various operations
- Dose validation and verification is a bottled neck for acceleration of commercialization
- Provide UV dose estimate to achieve target log reduction for organisms of concern: bio-dosimetry/actinometry/mathematical modelling
- Dosimetry have to be applicable to cover a broad range of doses and wavelengths in UV range (UVA, UVB, UVC) including polychromatic spectra
- Dosimeters can be used for FCS, solid food surfaces

Additional Resources published in 2019-22







Thank you

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