Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

BE 487 - Spring 2022
Biosystems Design Projects

BE 487 - Sterilization Analysis of Evaporator Coil Using UV-C Radiation for Industrial Food Processing Freezers (Under NDA)

Nyilah Congress, Ashley Xu, Shreyas Ramachandran, Nick Saba
Client: John Bean Technologies   Faculty Advisor: Dr. Sanghyup Jeong

Background

Introduction

JBT is a global leader in supplying technology solutions to high value segments of food processing systems. They develop, manufacture, and service solutions of the food production industry with a focus on proteins, liquid foods, and automated systems.

Sterilizing heat exchangers (evaporator coil) in an industrial food processing freezer is an important step to providing fresh and healthy food to customers. Heat exchangers are part of the freezers that exchange hot air with cool air, so that raw and packaged foods going through the conveyer belt in the freezers stay frozen. To prevent the freezers from contamination by foodborne pathogens, like *Listeria monocytogenes* a sanitation process is required. Therefore, these heat exchangers will need to be sterilized before the raw and packaged foods go through the freezing process.

Problem Statement

Perform experiments and produce data to provide proof of concept of ultraviolet sterilization, design suggestions, and an economic analysis

Significance

There are about 48 million cases of foodborne illness each year. Each year, these illnesses result in about 128,000 hospitalizations and 3,000 deaths. Young children, the elderly, and immunocompromised individuals are the most susceptible to serious illnesses. Foodborne microorganisms also pose a great threat to individuals in all age groups. To be certain foodborne microorganisms are eliminated from the freezer's evaporator coils, a sterilization process is implemented and occurs on a regular basis.

Objectives

- Reduce sanitation time
  - 1 hr currently
- Kill all foodborne pathogens; priority on *Listeria monocytogenes*
- Minimum of 5-log reduction
- UV-C energy fluence must reach $270\,\frac{mJ}{cm^2}$
- Reduce energy usage
- Reduce carbon footprint

Constraints

- Use UV-C radiation
- Follows American Conference of Governmental Industrial Hygienists (ACGIH)
- No mandatory regulations set (American Air and Water, n.d.)
- ACGIH published Threshold Limit Values (TLV)
- TLV for UV-C at 275nm is $0.0031\,\frac{mJ}{cm^2 - s}$ (American Air and Water, n.d.)

Recommendations

Design 1

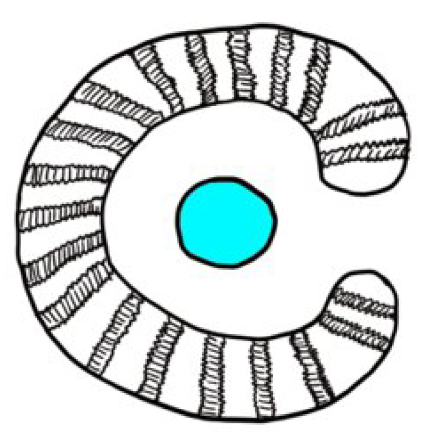

Figure 1: Circular coil design surrounding a UV-C bulb

Pros:
- Utilizes traditional UV-C bulbs
- UV-C irradiates whole tubing and fin
- Will reach center of coil

Cons:
- Requires redesign of current evaporator coil
- Need to be protected from freezing temperatures and water

Design 2

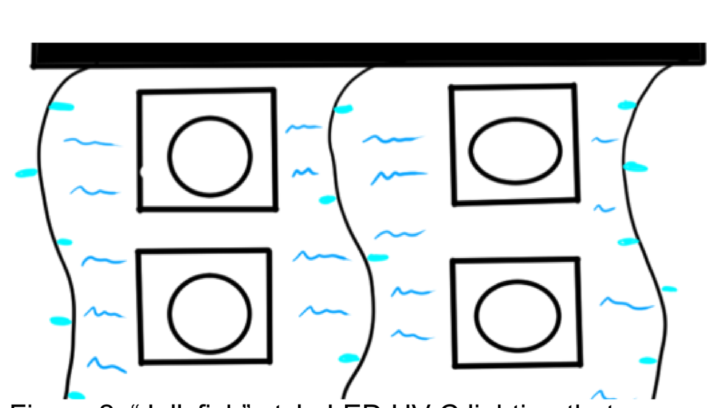

Figure 2: "Jellyfish" style LED UV-C lighting that goes into standard coil

Pros:
- LED strips; inexpensive
- Can be implemented with current design of coil

Cons:
- Delicate
- Need to be protected from freezing temperatures and water

Background

Ultraviolet-C Radiation

The UV light spectrum is undetectable to the human eye and has small wavelengths between 100 – 400nm (UCAR Center for Science Education, 2017). UV-C radiation is the highest energy radiation in its category, and ranges from 100 – 280nm. This is the only range in ultraviolet radiation that effectively and efficiently inactivates all foodborne pathogens (American Cancer Society, 2019). UV-C rays have recently established a widespread appeal with hospitals using them for sanitizing patient rooms, labs, and surgical operating rooms (Geiger, 2020). To reach a 5-log reduction, $500\frac{\mu W}{cm^2}$ is required (Kim, 2002).

Effects of Pulsating UV-C

- 200 light pulses, with duration of 100ns each
- Resulted in 6-log reduction with all types of foodborne pathogens (Demirci & Panico, 2008)

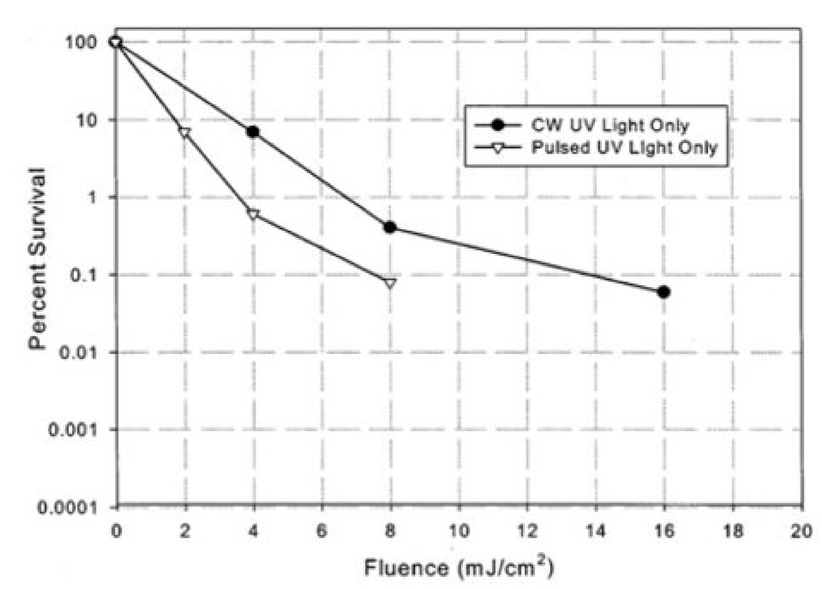

Figure 3: Depiction of pulsed and standard UV radiation fluence needed to reach a 6-log reduction (Demirci & Panico, 2008)

Inverse-Square Law

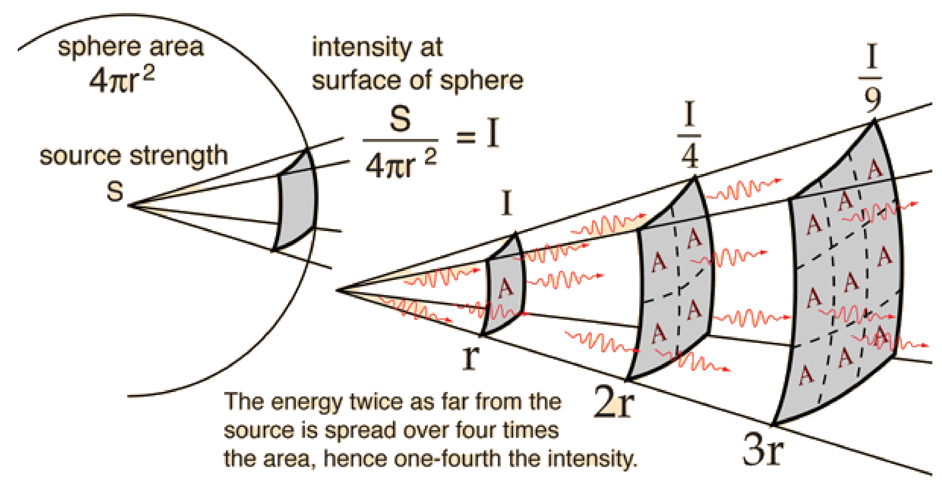

Figure 4: Depiction of the inverse square law of radiation

Experimental Design

Setup

***Experiment 1**:* Set up bulb directly above UV-C sensor and slowly move sensor away measuring each step to determine intensity
Purpose: Confirm if it follows inverse-square law

***Experiment 2**:* Lay experimental box and the bulb on its side with the bulb facing into the box to measure any reflected UV-C rays 1" from SS
Purpose: To qualitatively and quantitatively determine reflectivity values

***Experiment 3**:* Rest evaporator coil on blocks, enclose coil with experimental box, and measure readings underneath coil directly under bulb
Purpose: To determine dead spots throughout coil and horizontal range of traditional bulb

***Experiment 4(A,B)**:* Utilized dosimeter dots. Location of dots was placed on each level of tubes in coil
Purpose: To validate intensity values in experiment one and to determine location on coil where UV-C is not reaching

Results

Experiment 1

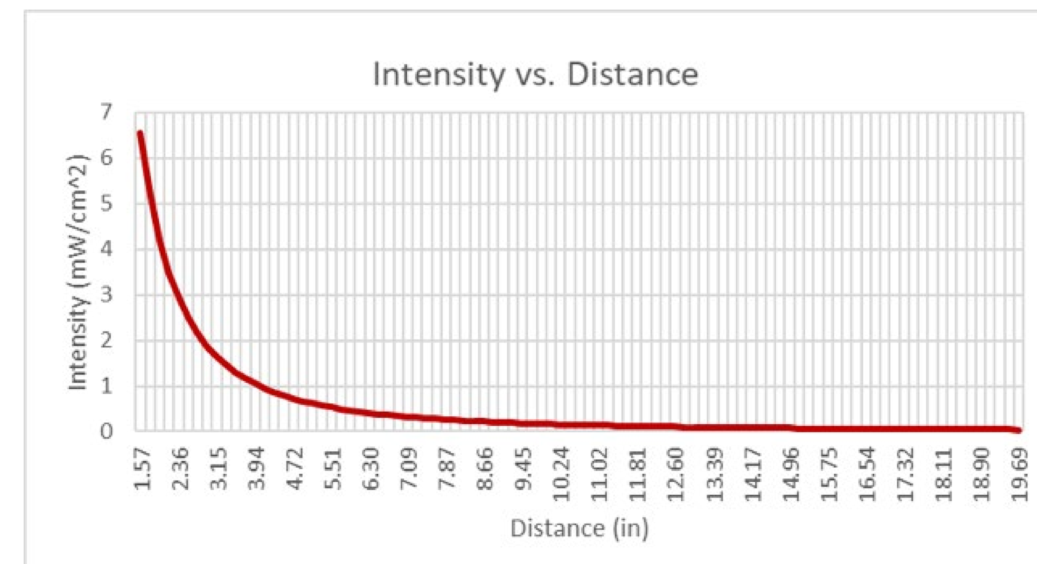

Figure 5: Measured and extrapolated data showing the relationship between UV-C intensity and distance which follows the inverse-square law

Experiment 2
- Near negligible reflectivity
- Value measured was $10\,\frac{\mu J}{cm^2}$

Experiment 3

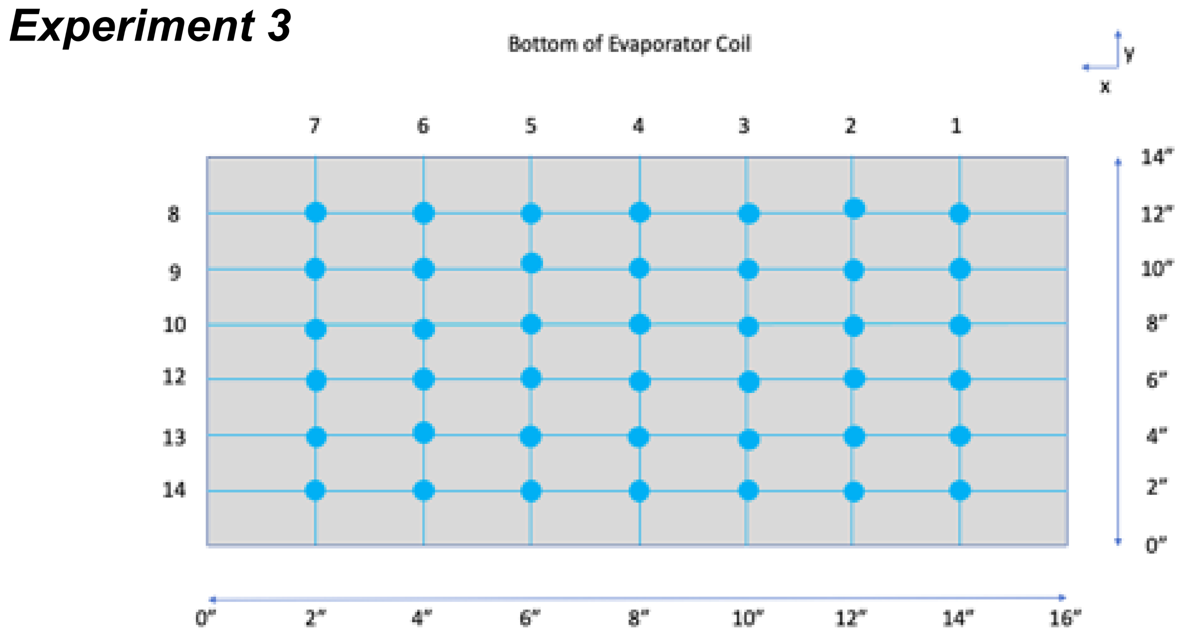

Figure 6: UV-C measured at the bottom of the coil with UV-C bulb on top. Blue spots indicate levels of UV-C radiation, while gray spots indicate lack of UV-C radiation

Experiment 4A

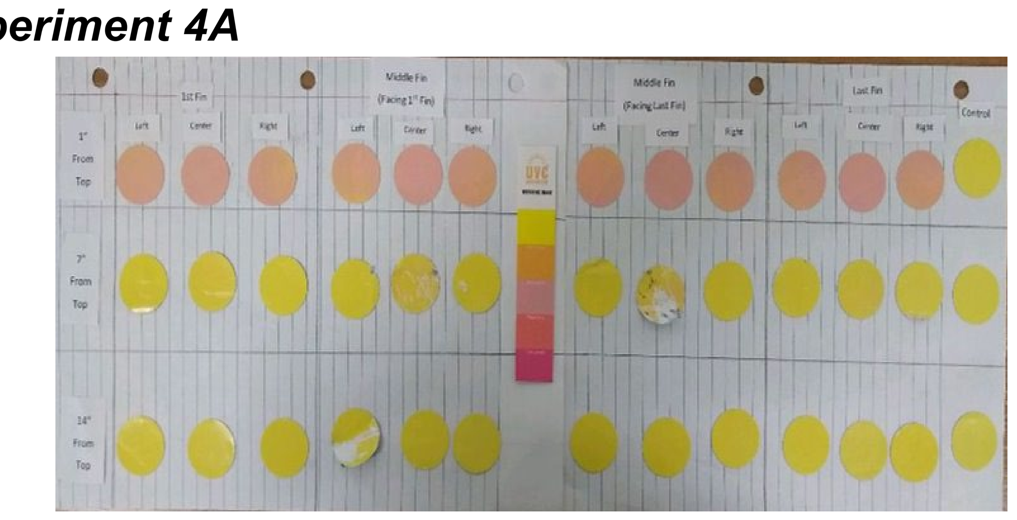

Figure 7: Dosimeter dots indicating qualitative level of fluence at indicated spots throughout coil

Experiment 4B

Figure 8: Dosimeter dots indicating qualitative level of fluence on the tubes within the coil

Economic Analysis

Steam Method Cost Analysis

- Main cost = steam generation
- Raise the temperature from 7.2°C to 62.7°C
- $13,630 annually
- Duration: 1 hr
- Frequency: 1 cycle/wk

Figure 9: Gyro-Compact Freezer analyzed for annual cost

UV-C Method Cost Analysis

- Main cost = electricity + initial purchase
- Use multiple UV-C bulbs to sanitize freezer
- $3,398 annually ($168,000 for max UV using 1,400 bulbs)
- Duration: 1 hr
- Frequency: 1 cycle/wk

References

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Geiger, D. (2020, April 28). UV light helps Duke Hospitals fight transmission of superbugs. Duke Health. https://www.dukehealth.org/blog/uv-light-helps-duke-hospitals-fight-transmission-of-superbugs.

Kim, T., Silva, J. L., & Chen, T. C. (2002). Effects of UV irradiation on selected pathogens in peptone water and on stainless steel and chicken meat. *Journal of Food Protection*, *65*(7), 1142–1145. https://doi.org/10.4315/0362-028x-65.7.1142