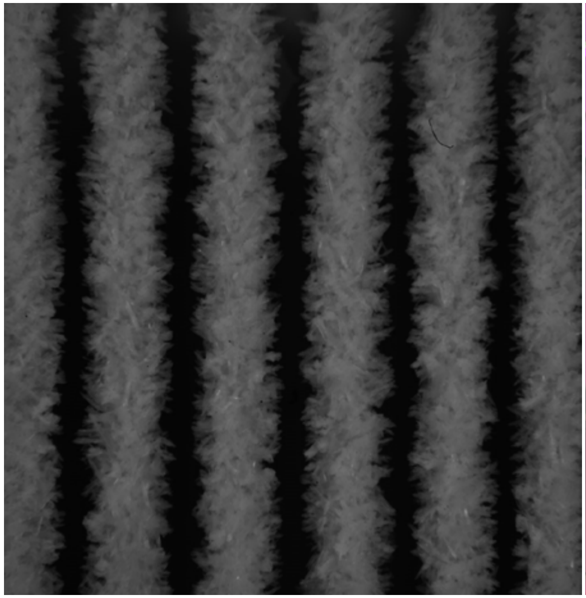
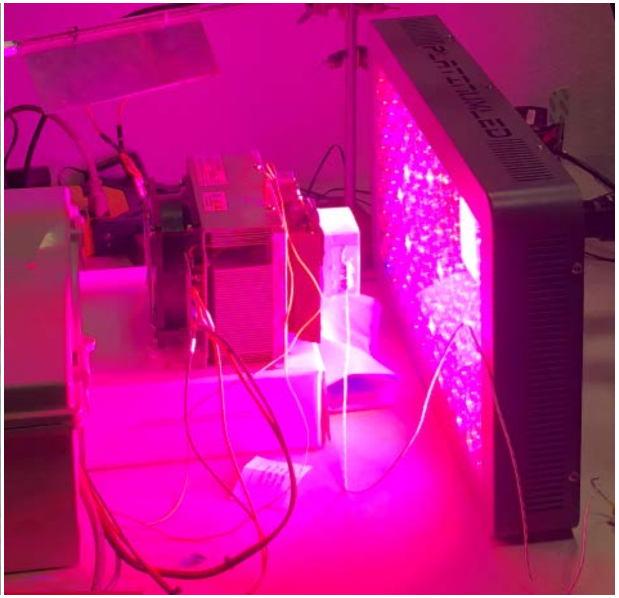
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Radiation Defrosting Technique





Oak Ridge National Laboratory
Kashif Nawaz- Research Staff
865-241-0972 nawazk@ornl.gov

Project Summary

Timeline:

Start date: 10-01-2017

Planned end date: 09-30-2020

Key Milestones

Evaluation of defrost/frost mitigation methods.

Analysis of frost growth process on surfaces.

Impact of radiation wave length on defrost.

Budget:

Total Project $ to Date:

- DOE: $115,000

Total Project $:

- DOE: $590,000

Key Partners:

Johnson Controls Inc.

Hillphoenix

University of Illinois at Urbana Champaign

Isotherm Inc.

Project Outcome:

A novel, cost effective and energy-efficient approach to enhance the defrost process for cold climate heat pumps and commercial refrigeration systems utilizing radiations.

Team

BTRIC (ORNL)

Academic institutions

CNMS (ORNL)

Industrial partners

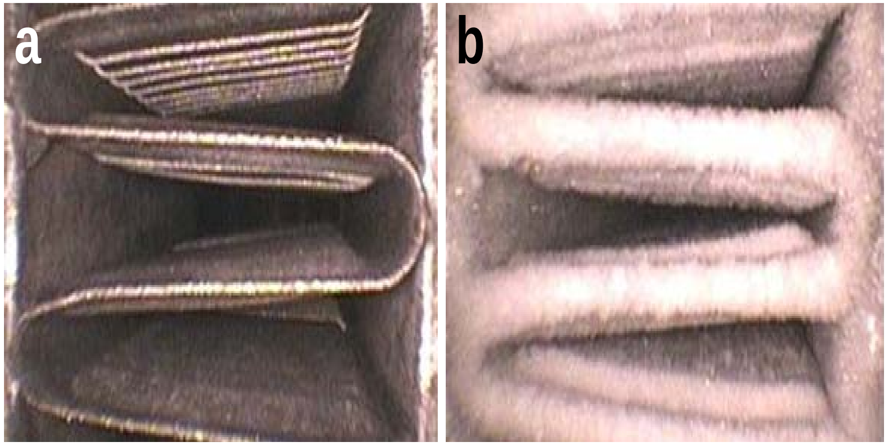
Challenge and Impact

Frost formation presents a challenge for both the heat pump and the refrigeration industry, and in both commercial and residential applications.

Frost buildup increases pressure drop (fan power) and decreases heat transfer, due to the reduced air flow area and thermal conductivity when compared to the base heat exchanger material.

The efficiency degradation due to frost growth, and the energy required to defrost, can account for 15-25% of the annual electric energy consumption by heat pumps.

The development of effective frost mitigation and defrost technology can lead to more than 200TBtu/year of U.S. primary energy savings.



Microchannel sample under frosting conditions. Images (a) and (b) represent times of 0 and 8 minutes, respectively, after starting the test. T_{surface} = -8°C and T_{air} = 1.7/0.6°C $T_{\text{db}}/T_{\text{wb}}$.

A heat pump outdoor coil covered with frost

Approach

Air conditions (frost growth rate, defrost energy)

Frost growth/defrost process

Surface morphology (frost density, adhesion to surface, condensate drainage)

Fin geometry (frost growth rate, drainage behavior)

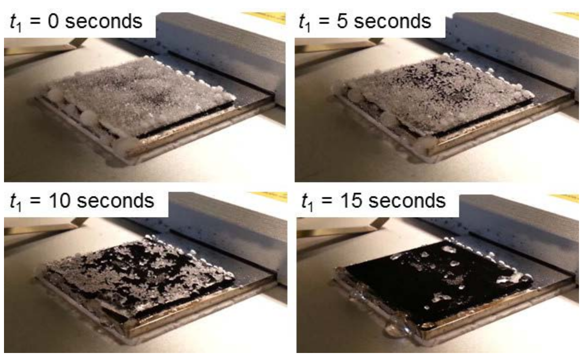
Evaluate the potential of radiation-based defrost (Microwaves, UV, visible) processes for deployment in cold climate heat pumps and commercial refrigeration.

- **Radiation defrost can provide an novel approach with significantly lower energy requirements, the process can be accomplished continuously or intermittently.**
- **In order to evaluate the impact, its important to:**
  - I. Characterize the frost growth on various surfaces
  - II. Analyze various radiation sources for appropriateness for proposed application (interaction with air, bare surface and surface with frost).

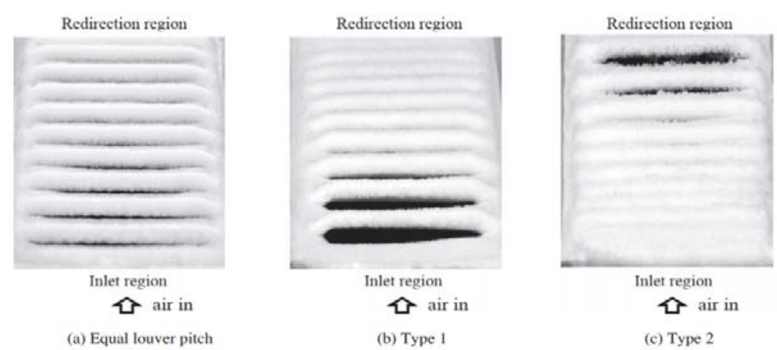
TRL 2→ TRL 5

Progress - Overview of existing technology

Frost Mitigation Techniques	
Upstream air treatment	1. Reducing inlet air humidity 2. Preheating inlet air 3. Increasing inlet airflow rate
Heat exchanger modifications	1. Adjusting fin and tube geometry 2. Fin type selection 3. Coating treatment on fin surface
System Modification	1. Vapor-injection technique 2. Two-stage technique 3. Adding outside heating source 4. Adjusting refrigerant distribution



Oil infused SLIPS can assist the condensate removal after defrost.



Variable louver angle/pitch fins can mitigate the adverse effect of frost growth better than those with uniform geometry.

Progress - Overview of existing technology

Method	System complexity	System stability	Frost mitigation	Scalability	Capital cost	Operational cost
Preheating the air stream	High	High	High	Moderate	High	High
Increasing air flow rate	High	High	Moderate	Moderate	High	High
adjusting fin geometry	Low	High	Moderate	High	Moderate	Low
Fin type selection	Low	High	Low	High	Moderate	Low
Surface morphology for fin surface	Moderate	High	Moderate	Moderate	Moderate	Low
Vapor injection technique	High	Low	Moderate	Low	High	Moderate
Two stage technique	High	Low	Moderate	Low	High	Moderate
Adding outside heat source	Moderate	Moderate	Moderate	Moderate	Moderate	High
Adjusting refrigerant distribution	Low	High	Moderate	Moderate	High	Low

Most of the existing frost mitigation methods have limited implications due to scalability, durability and cost issues.

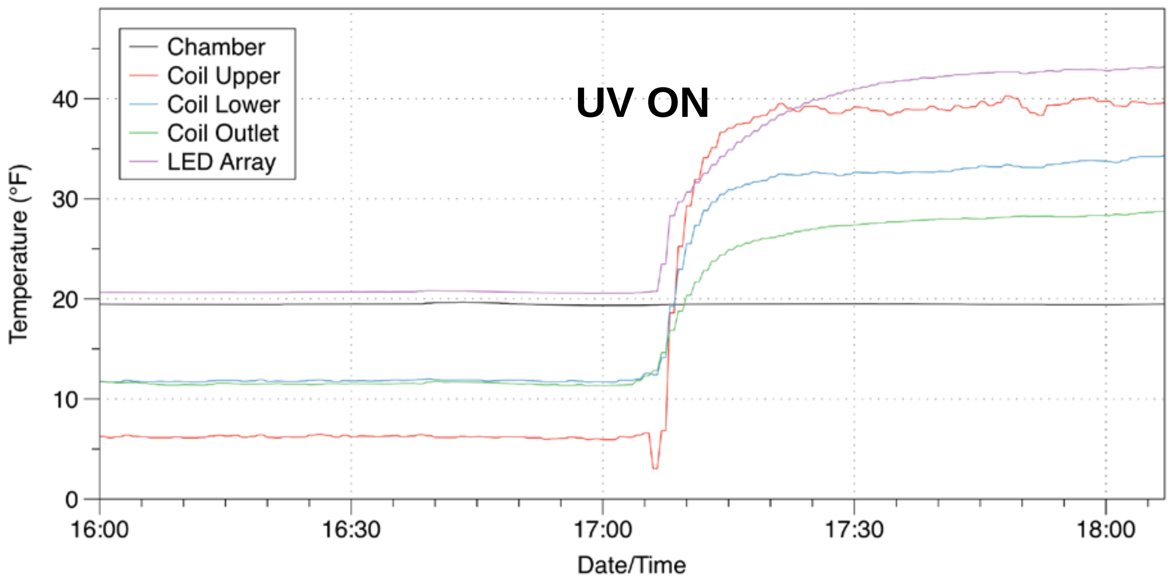
Progress - Overview of existing technology

Defrost techniques	
Defrost by cycle interruption	1. Compressor shutdown 2. Electric heating 3. Hot gas bypass 4. Reverse cycle
External source based defrost	1. Hot water spraying defrost 2. Air jet defrost

Method	Compressor	Thermal source	System complexity	System stability	Defrost effect	Scalability	Efficiency degradation
Compressor shutdown	OFF	Ambient air	**Low**	**High**	**Low**	**High**	**Moderate**
Electric heater	OFF	Electric power	**High**	**High**	**High**	**Moderate**	**High**
Hot gas bypass	ON	Electric power	**Moderate**	**Moderate**	**Moderate**	**Low**	**Moderate**
Reverse cycle	ON	Electric power	**High**	**Low**	**High**	**Low**	**High**

Cycle interruption defrosts are the most commonly deployed methods to remove frost from the heat exchanger surface.

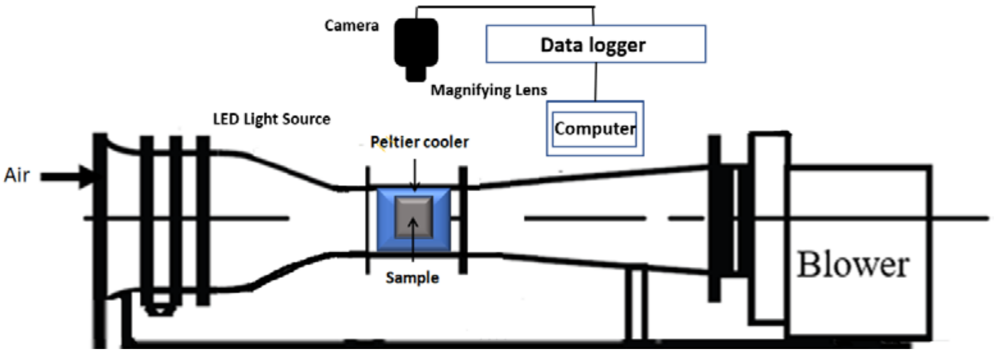
Progress - Radiation defrost process
(Preliminary analysis)



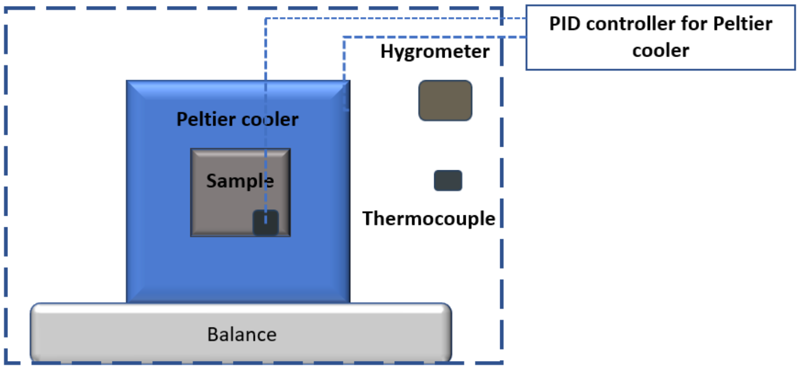
Indoor conditions: 50° F, 75% RH
Operation time (frost growth): 6 hrs.
Defrost time: 40 minutes (with UV); 60 minutes (without UV)
Radiation flux=200 W/m^2
Condensate container weight:

Pre-defrost: 1.075 lb.
Post-defrost: 2.175 lb.
Condensate collected: 1.100 lb.

Progress - Analysis of frost growth process



Open loop wind tunnel placed in controlled environmental chamber for forced convection experiments



Peltier cooler based apparatus placed in controlled environmental chamber for natural convection experiments

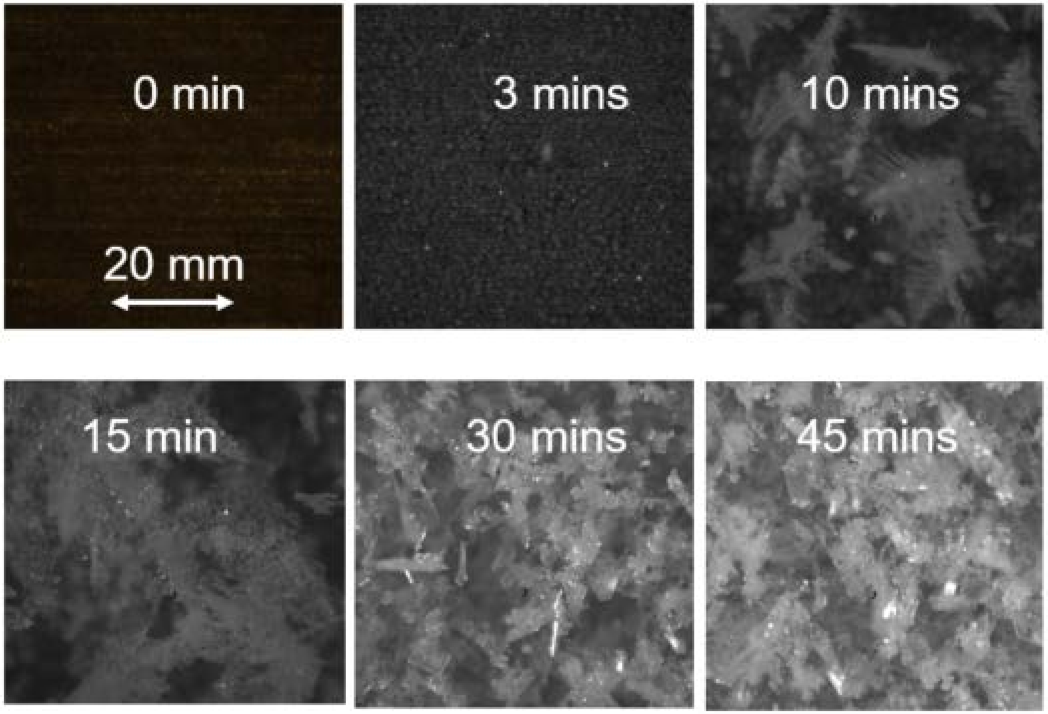
Experiments classification

- Frost growth process
- Natural/forced convection defrost process
- Radiation assisted natural/forced convection defrost process

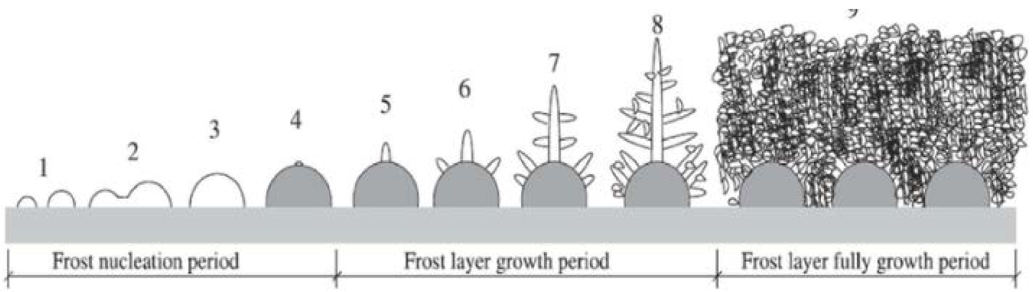
Parameters of interest

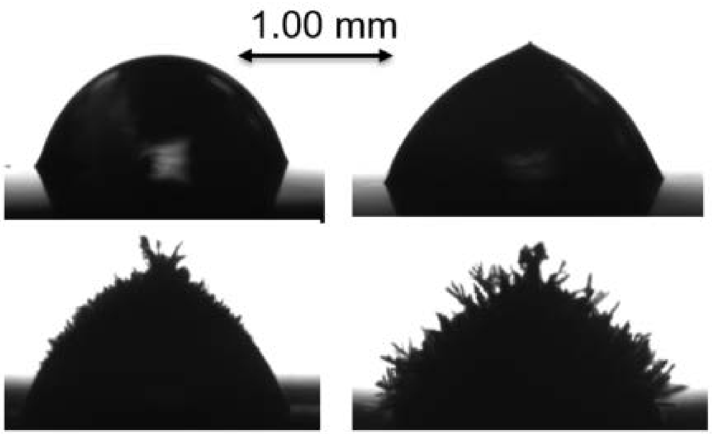
- Frost density, thermophysical properties (conductivity, specific heat, latent heat), Radiation properties (absorptivity, emissivity)
- Energy required for defrost process
- Time required for defrost process

Progress - Analysis of frost growth process

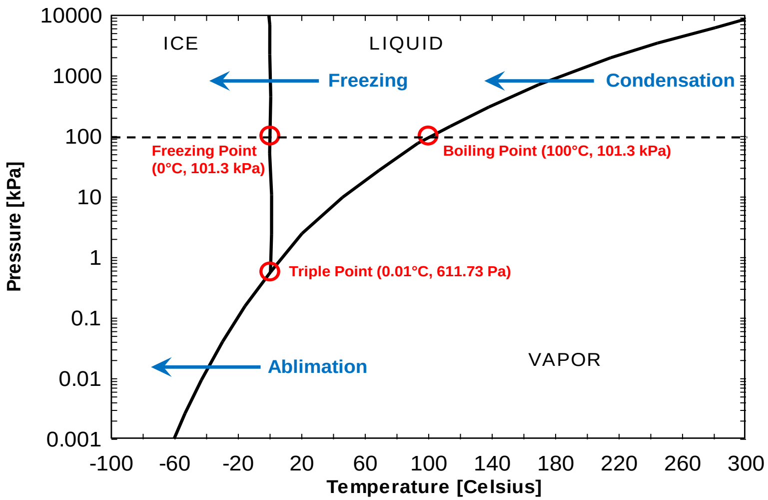


Natural convection 40°F (DB), 37°F (WB)
Baseplate temperature 12°F



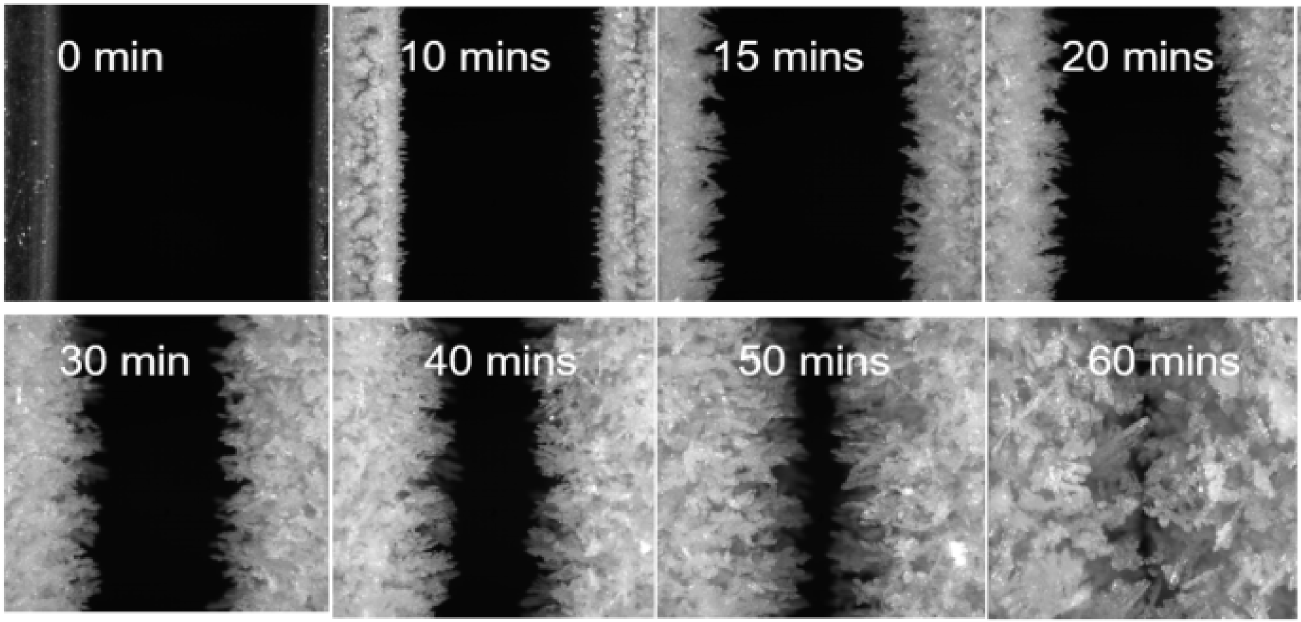


Frost growth process on a cold plate

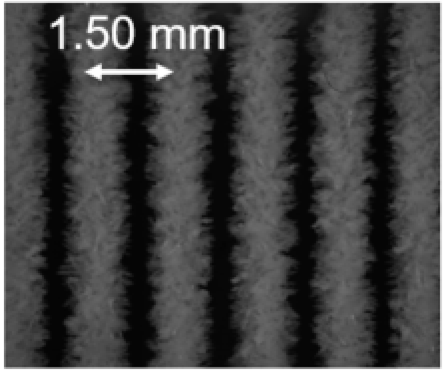


Phase change processes

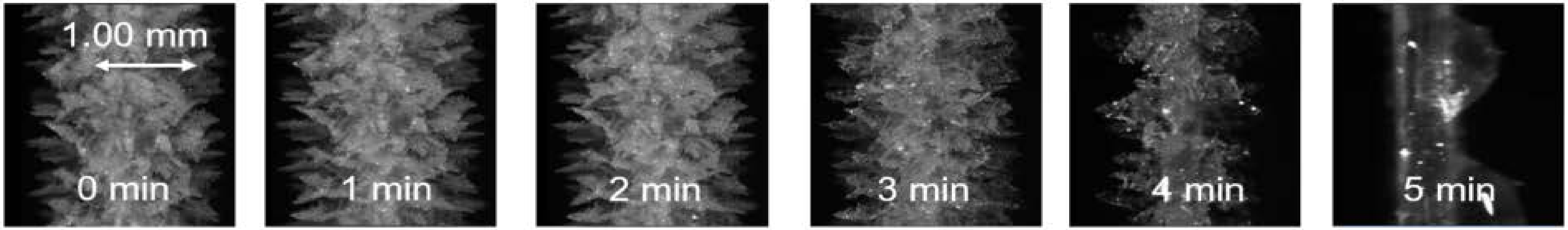
Progress - Analysis of frost growth process



Frost growth on extended surface



Extended surface

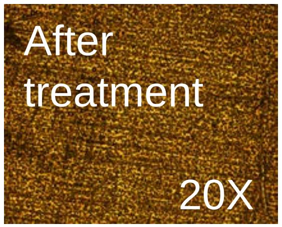


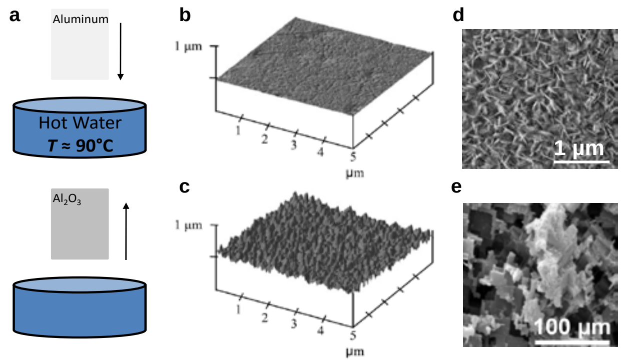
Natural convection 40°F (DB), 38°F (WB)
Baseplate temperature 12°F

Defrost on extended surface

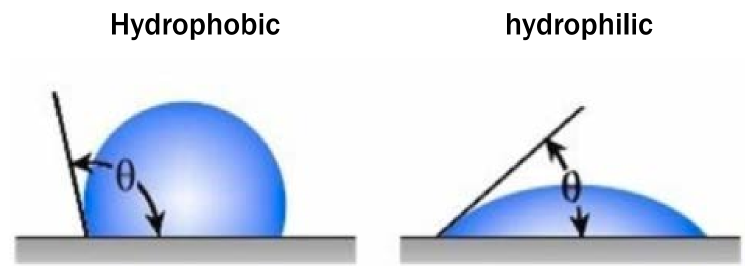
Progress - Analysis of frost growth process

(Treated vs. untreated surfaces)





Boehmite process to alter surface morphology



Definition of contact angle

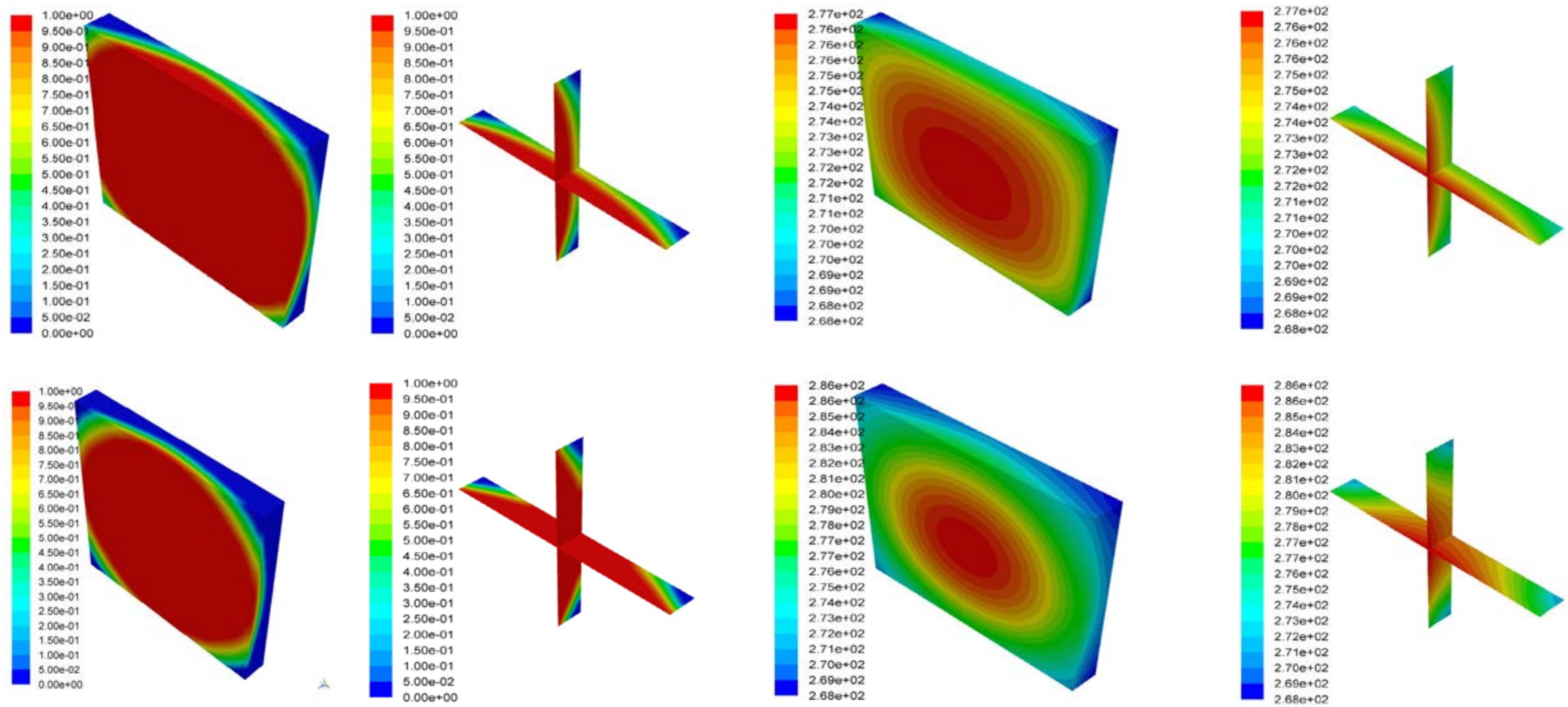
Treatment type	Contact angle (º)	Frost density (kg/m^3)
Bare aluminum	50.90	495
Bare copper	75.20	355
Acid etching-aluminum	37.70	560
Acid etching-copper	64.50	450
Boehmite process-aluminum	90.50	255
Boehmite process-copper	94.40	305
Saline coating-aluminum	88.40	310
Saline coating-copper	75.80	365

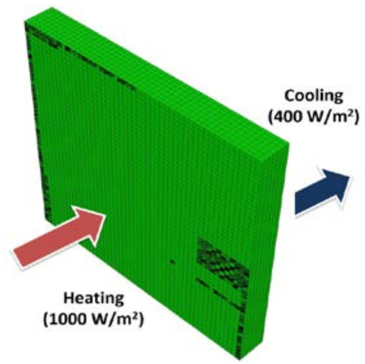
Progress - Radiation defrost (CFD analysis)
(Preliminary analysis)

Liquid fraction (-) | Temperature profile (K)

Case 1

Case 2



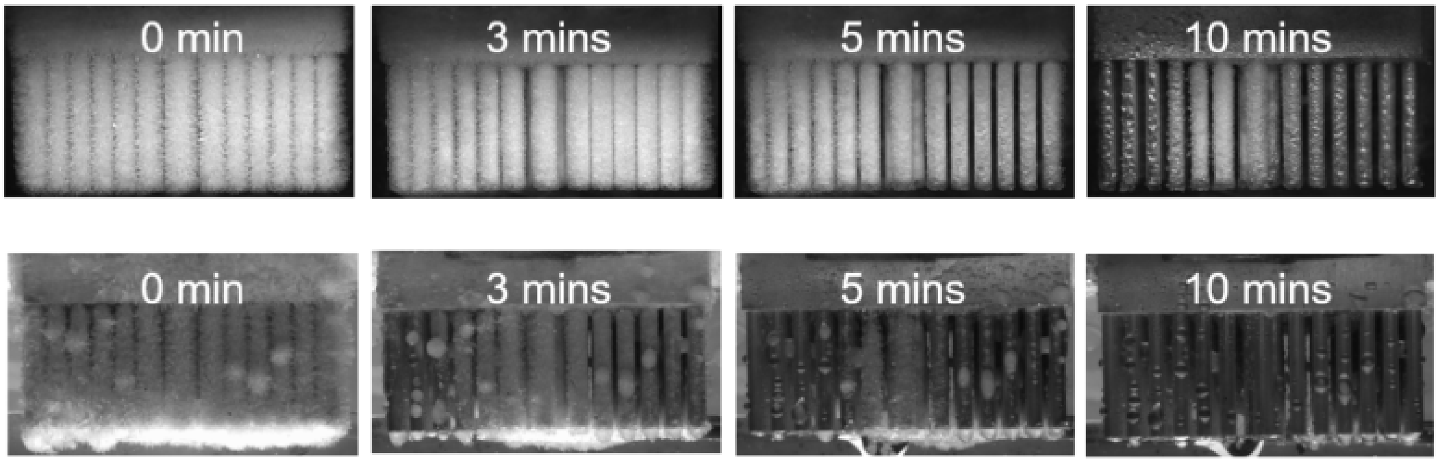


Case	Density (kg/m^3)	Thermal Conductivity (kJ/kg. K)
1	450	0.55
2	300	0.325

Progress - Radiation defrost (Experiments)
(Preliminary analysis)

Forced convection
(No radiations)

Forced convection
(200 W/m^2)



Indoor conditions: 42^{o}F (BD), 37^{o}F (WB)
Baseplate temperature 12^{o}F
Face velocity: 1 m/s
Operation time (frost growth): 1.5 hrs.
Defrost time: 10 minutes (Forced convection only)
Defrost time: 6 minutes (Forced convection and UV radiations)
Radiation flux: 200 W/m^2

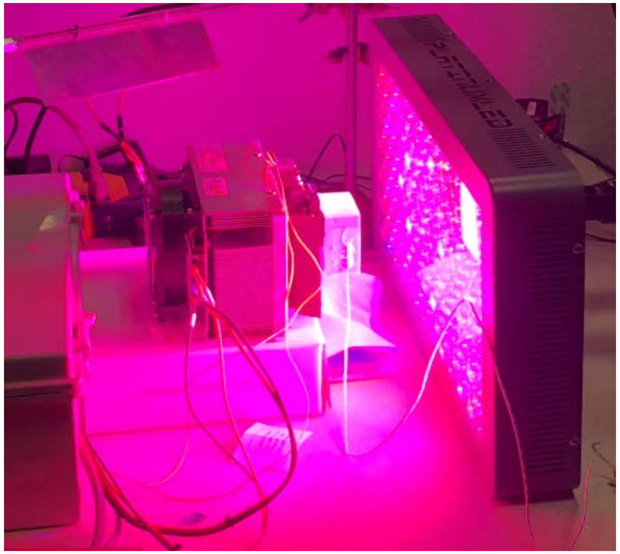
Work in Progress and Future Tasks

Work in progress

1. Frost growth characterization and defrost under forced convection- impact of fin profile, air conditions and flow rate.
2. Development of frost growth model based on surface contact angle, surface temperature, air conditions.
3. Characterization of radiations (wave length, intensity, flux etc.).
4. Radiation (UV) assisted defrost characterization under natural/forced convection.

Future tasks

1. Radiation (Microwaves) assisted defrost characterization under natural/forced convection.
2. Radiation (Visible) assisted defrost characterization under natural/forced convection.
3. Development of performance model for radiation defrost.



Thank You

Oak Ridge National Laboratory
Kashif Nawaz- Research Staff
865-241-0972 nawazk@ornl.gov

REFERENCE SLIDES

Project Budget

Budget Details					
FY 2018 (current)		FY 2019 – (planned)		FY 2020 – (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
350,000		120,000		120,000	

Project Plan and Schedule