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Effect of Surface Omniphobicity on Drying by Forced Convection

Madani Khan
The City College of New York
STAR Program
August, 2015
Background

• I am from Bangladesh.
• Education: The City College of New York
  • Major: Chemistry; Minor: Education.
Abstract

• Low energy surfaces can strongly repel both oil and water. Recently these surfaces have been fabricated on various substrates including fabric, aluminum, stainless steel and many other materials. In this experiment we explore the use of low energy surface deposition on aluminum alloy, stainless steel and silicon substrates, to enhance the drying rate of liquids removed from the surface by forced convection. We control surface roughness by substrate abrasion and by the growth of Al$_2$O$_3$ nanograss to enhance liquid repellence by use of a hierarchical texture. Liquid repellence of the substrates is measured by contact angles of the probe liquids, water and hexadecane. Samples are mounted on a rigid stage constructed with a flat surface and a regulated air nozzle fixed to provide flow parallel to the substrate surface. The velocities of probe liquid droplets placed on the substrates are recorded via high-speed camera as they are moved by a constant air flow. It is shown that drops on omniphobic and superomniphobic surfaces move at increased velocity compared to untreated surfaces, and leave behind less residual liquid, resulting in a faster drying rate. 2-factor design of experiments (DOE) was implemented to explore the optimum conditions for a fast drying low energy surface. The use of DOE and the results of this experiment are merged into a lesson plan developed for 9$^{th}$-12$^{th}$ grade students. These results will serve as examples low energy surfaces and their potential applications.
Introduction

• Explore the use of low energy surface deposition on aluminum alloy, stainless steel and silicon substrates, to enhance the drying rate of liquids removed from the surface by forced convection
• The velocities of probe liquid droplets placed on the substrates are recorded via high-speed camera as they are moved by a constant air flow
• 2-factor design of experiments (DOE) is implemented to explore the optimum conditions for a fast drying low energy surface
Application

• The application of this work can be used in rocket engines, rooftops, cars, umbrellas, tiles, oven, paint, or any kind of fabrics.
Design of Experiment (DOE)

• Systematic method to determine the relationship between factors affecting a process and the output of that process.

• Why?
  – Saves time
  – Lower cost
  – Reduce product material and labor complexity
  – Better design engineering

• Accessibility
  – Microsoft Excel or online software
Substrates

Stainless Steel

Aluminum

Silicon Wafer
Roughness Values

Roughened Surface Crossly Sanded with Grit Size 2000

- $R_a$ - Roughness Average (499.97nm)
- $R_q$ - Root Mean Square (624.58 nm)
- Sm - Surface Material Volume (26.36 nm$^3$/nm$^2$)
- Sv - Surface Void Volume (66.06 nm$^3$/nm$^2$)
Contact Angle

155° 155°
Gas-Flow System
High-speed Video
Result

Roughness vs. Drying Time

Boiling Time vs. Drying Time

Time (sec)

Grit 1200  Grit 320
Roughness

sec/cm

Time (sec)

2 min  5 min
Boiling Time

sec/cm
Conclusion

• Lower roughness leads to faster drying time.
• An irregular surface can cause pinning regardless of silanization and contact angle, which disturbs the trend of hysteresis.
• Higher boiling time leads to faster drying time.
• Water has a faster drying rate than hexadecane.
Lesson Plan

• This lesson plan is directed for 9th-12th grade students.

• Reading about ice-cream.

• Learning to make ice-cream through a DOE optimization.

• The three factors are different weight percent of salt per ice, fat content in dairy and shaking time.

• Measured output will be rating and average of different ice-creams.
Future Work

• Different type of liquids
• Durability
• Using the optimization from DOE to further explore factors.
Acknowledgement

- Funding and support was received by the STAR program and thank you to the AFRL for a great research experience. Thank you to Dr. Jeffrey Alston and Dr. Andrew Guenther for all their guidance and encouragement throughout this project. And a special thanks to my fellow STAR student: Nicholas Rubel.
Questions?
Flow System

AI Substrate

Flow Cell
Creating Reentrant Surface

Before Sanding
After Sanding

Micro-scale

$\mu m$
Nano-grass Growth

Nano-scale

μm

Nano-grass

Air
Low Surface Energy

Low Surface Energy

PFDTS

μm

PFDTS

PFDTS

PFDTS

PFDTS

PFDTS

PFDTS
Flow System

Al Substrate

Flow Cell
Trapping Plastron

Dry

Under Water