Laboratory Evaluation of Potential Condenser Improvements

Rebecca Osteen, Southern Company Research & Development
Andrew Howell, EPRI
Brian Dumont, Airflow Sciences Corporation

Southern Company

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Airflow Sciences Corporation

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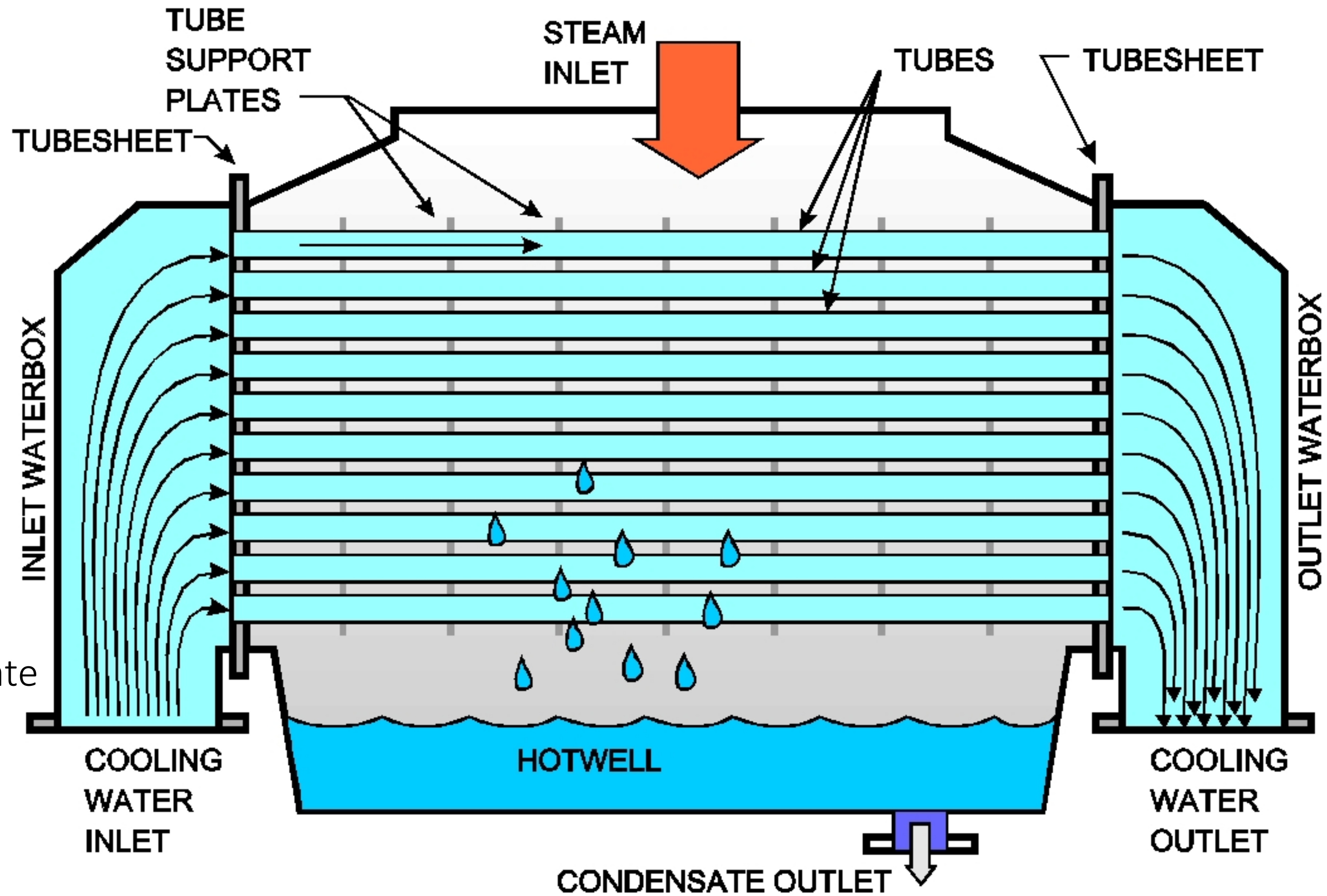
Project Overview

<u>DOE Project Title:</u> Investigation of Technologies to Improve Condenser Heat Transfer and Performance in a Relevant Coal-Fired Power Plant

- Prime Recipient: Electric Power Research Institute (EPRI)
- Other Participants: Southern Company, Clean Air Engineering, Airflow Sciences Corporation
- Project Duration: 3 years
- Total Funding: $2.5M

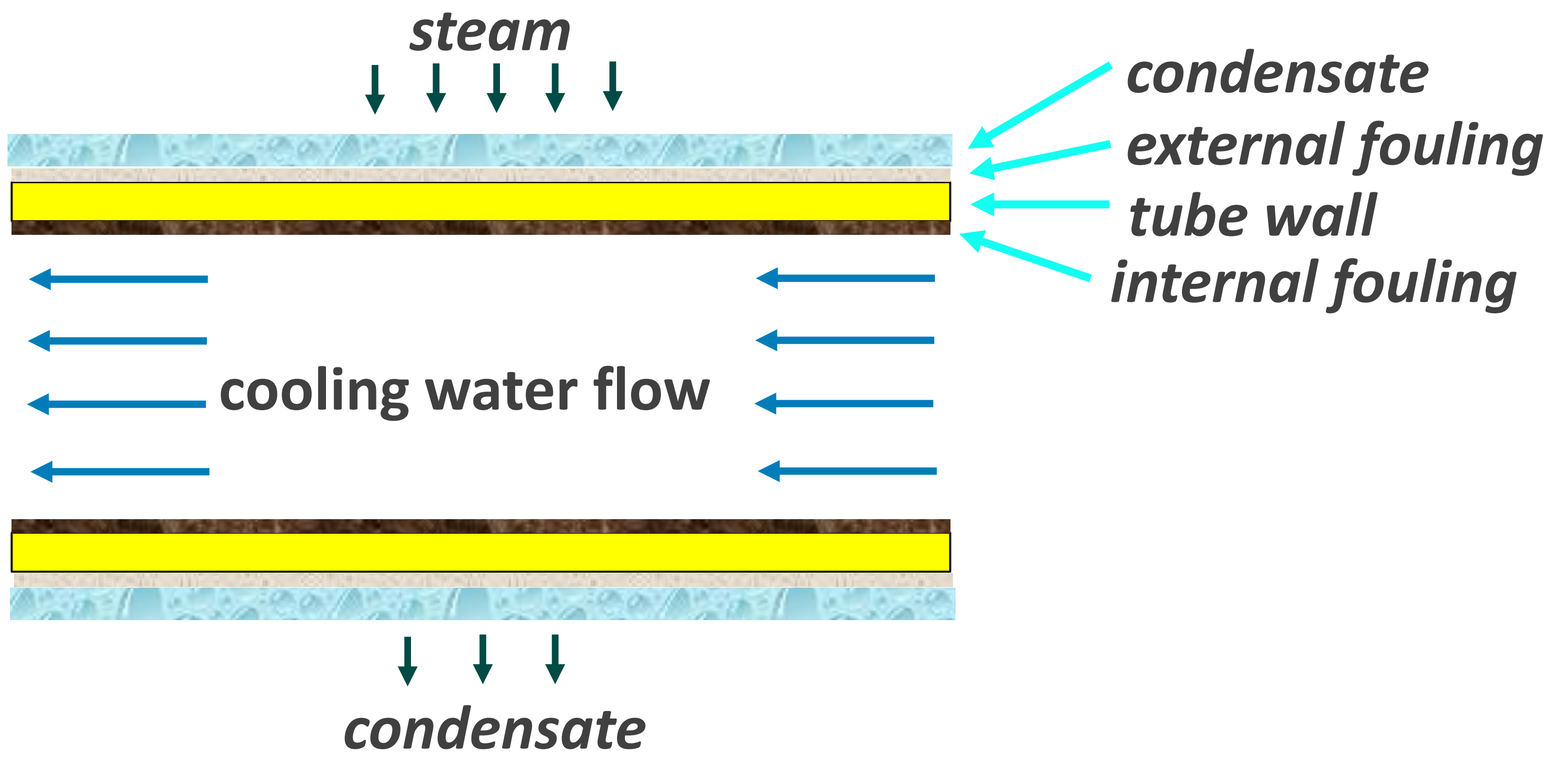
Condenser Performance – An Overview

- Barriers to heat transfer
  - Internal Fouling
    - » Biofouling
    - » Scaling
  - External Fouling
  - Thermal Conductivity of Tube (small)
- Heat Transfer Enhancements On the Market
  - Internal
    - » Surface treatments to prevent fouling
    - » Prediction of fouling
    - » Boundary Layer disruption
  - External
    - » Surface treatments to enhance shedding of condensate
- ***Do They Work? Do They Last?***



Condenser Tube Fouling

- Problems caused by fouling:
  - Reduces heat transfer and plant efficiency
  - Can lead to corrosion and tube failure and consequently…
    - » Result in contamination of high-purity steam cycle water
    - » Require an outage to address the leak
  - Can require outage to remove foulant(s)

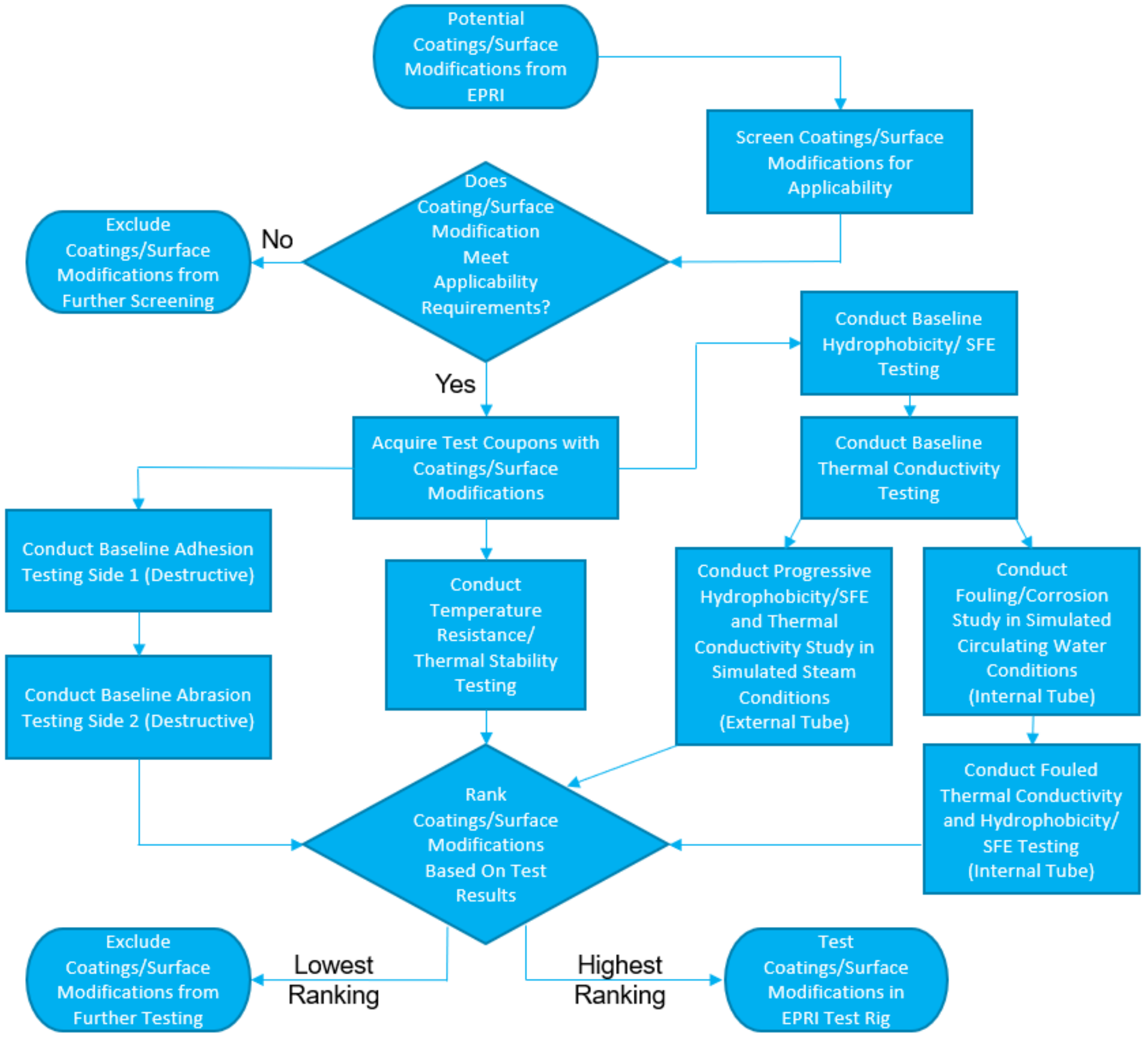


Project Objectives

- Evaluate application of various surface modification technologies on thermal power plant condenser tubes to enhance heat transfer properties and overall performance
- Coating technologies and materials applied to heat exchanger tubes to modify and enhance the heat transfer characteristics
- Testing of full-scale modified tubes performed in an environment simulating that in fossil-fired power stations
- Supporting objectives included:
  - identification of potentially suitable coatings/modifications to test
  - laboratory testing to identify key modification characteristics both pre- and post- environmental exposure
  - heat transfer testing and performance evaluations

Project Process

- Lab Testing: Evaluate the characteristics of coated titanium coupons to confirm applicability (ASTM procedures)
  - hydrophobicity
  - durability
  - adhesion
  - thermal conductivity
  - effect of temperature
- Field Testing: Provide three new 17-foot, 1” O.D. titanium tubes to each vendor for application of coating
  - Install and measure heat transfer coefficient initially and over time
  - Focus on microbiological fouling for internally coated tubes



Test Facility: WRCC

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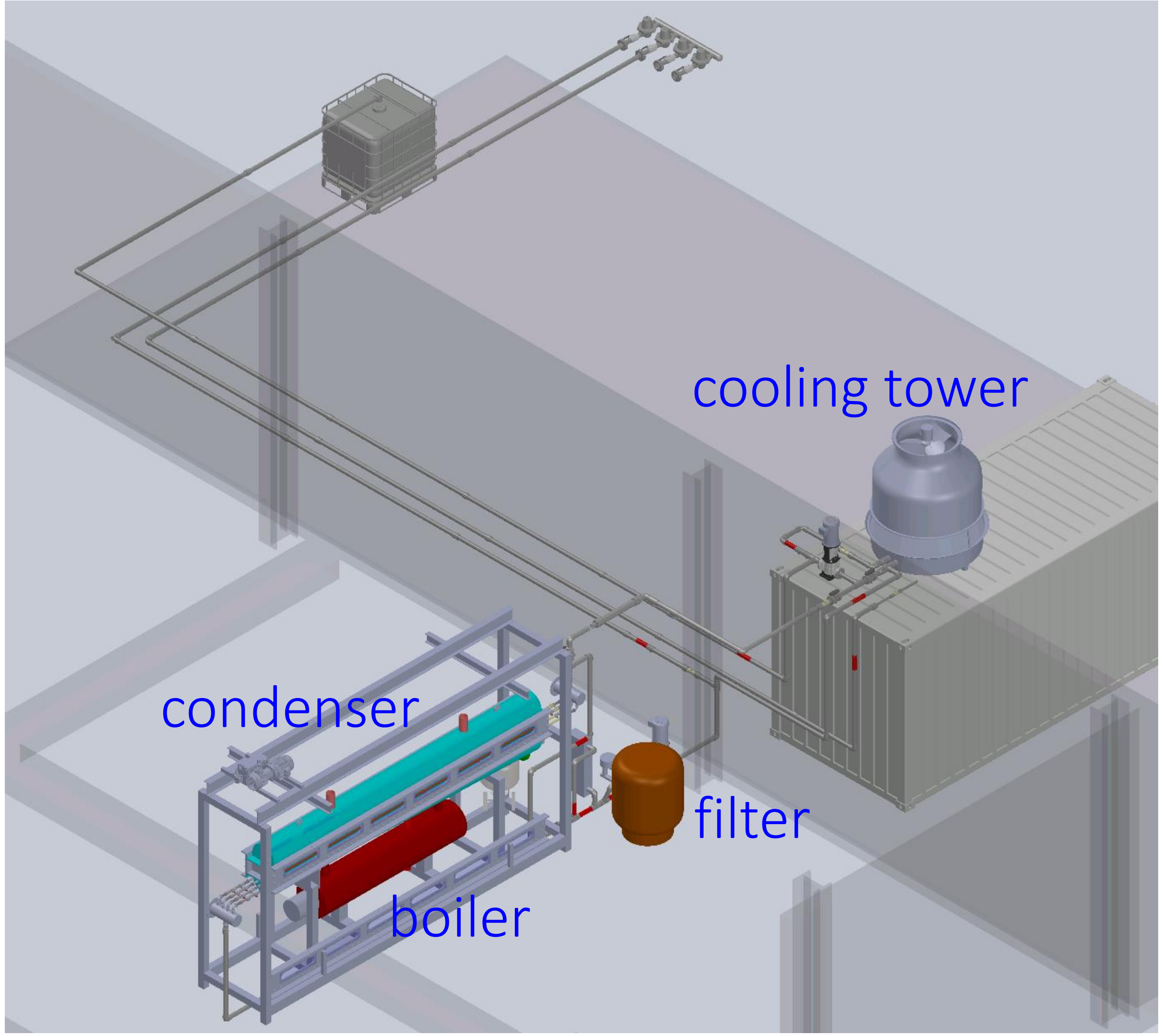
Water Research and Conservation Center (WRCC)

- Comprehensive test center to expand cooling system and heat transfer research
- On-site at Georgia Power Plant McDonough
- Can support multiple concurrent tests
- Objectives and Scope
  - To address mid- to long-term needs in power plant cooling applications
  - Cooling R&D focused on advanced and alternative cooling systems, cooling water chemistry control, and heat transfer improvements
- Value
  - Accelerate technology development to meet anticipated future needs
  - Address research gaps to facilitate development of technologies that provide cost-effective solutions
  - Reduced water withdrawal and consumption for thermoelectric cooling
  - Improved heat transfer and plant efficiency

WATER
Research & Conservation
Center

WRCC Heat Transfer Loop (HTL)

- Cooling cycle designed to mimic plant cooling cycle
- Includes both steam side and cooling water side
- Well instrumented
- Condenser
  – 4 tubes, 15ft long, up to 1”diameter
- Boiler
  – 300kW electric
- Cooling Tower
  – 30 ton
- Can control chemical additions
- Has optional sand filtration



WRCC Heat Transfer Loop (HTL): Condenser

WRCC Heat Transfer Loop (HTL): Boiler

WRCC Heat Transfer Loop (HTL): Cooling Tower

WRCC Heat Transfer Loop (HTL): Operating Parameters

- Cooling loop:
  - positions for up to four 4.6 meter (15 foot) length condenser tubes with outside diameter 19.1 to 25.4 mm (0.75 to 1.0 inches)
  - target flow 2.1 mps (7 fps) through condenser tubes with temperature rise of 8.3 °C (15 °F)
  - cooling tower operated for a target condenser inlet temperature of 26.7 – 37.8 °C (80 – 100 °F)
- Steam generator:
  - condensing steam increases the temperature of cooling water and develops a significant steamside vacuum
  - the high-purity steam condensate is recirculated for re-use in the boiler
- Heat transfer measurement:
  - parameters necessary to calculate the heat transfer coefficient are measured with permanent instrumentation including flow, pressure, and temperature of the cooling water in each tube as well as the bulk measurements
  - for testing purposes, biofilm formation was selected as the mode of fouling
  - an unmodified tube was included in each test along with three modified tubes

WRCC Heat Transfer Loop (HTL): Condenser Tube Arrangement

Internal Anti-fouling Treatments

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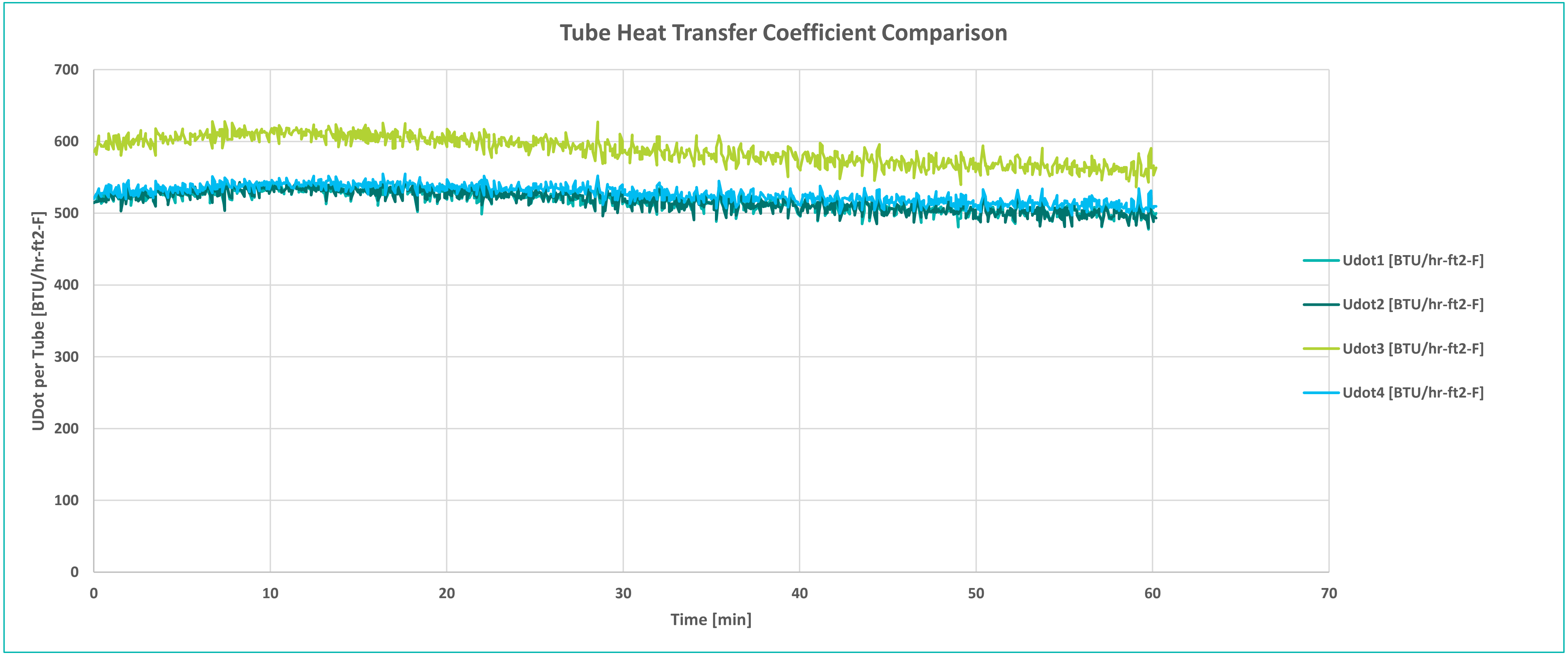
Microbiological Fouling Test Conditions

- Testing of internal anti-fouling treatments looks for changes over time at representative test conditions
  - Looks at ratio of heat transfer coefficients between treated and plain tubes
  - Over 1.0 means the treatments are outperforming a plain tube
  - Under 1.0 means the plain tube is outperforming the treated
  - Between tests, promote the type of fouling we want to study (typically biofouling)
- Initial heat transfer test to evaluate heat transfer resistance of the coating
- Conditions to support biofilm formation:
  - Discontinue biocide feed
  - reduce flow rate by 50%
  - stagnant periods included, typically weekends
  - bucket set aside for micro-organism growth
  - in-line sand filter bypassed
  - side-stream loop with stainless steel mesh coupons included for biofilm growth tendency

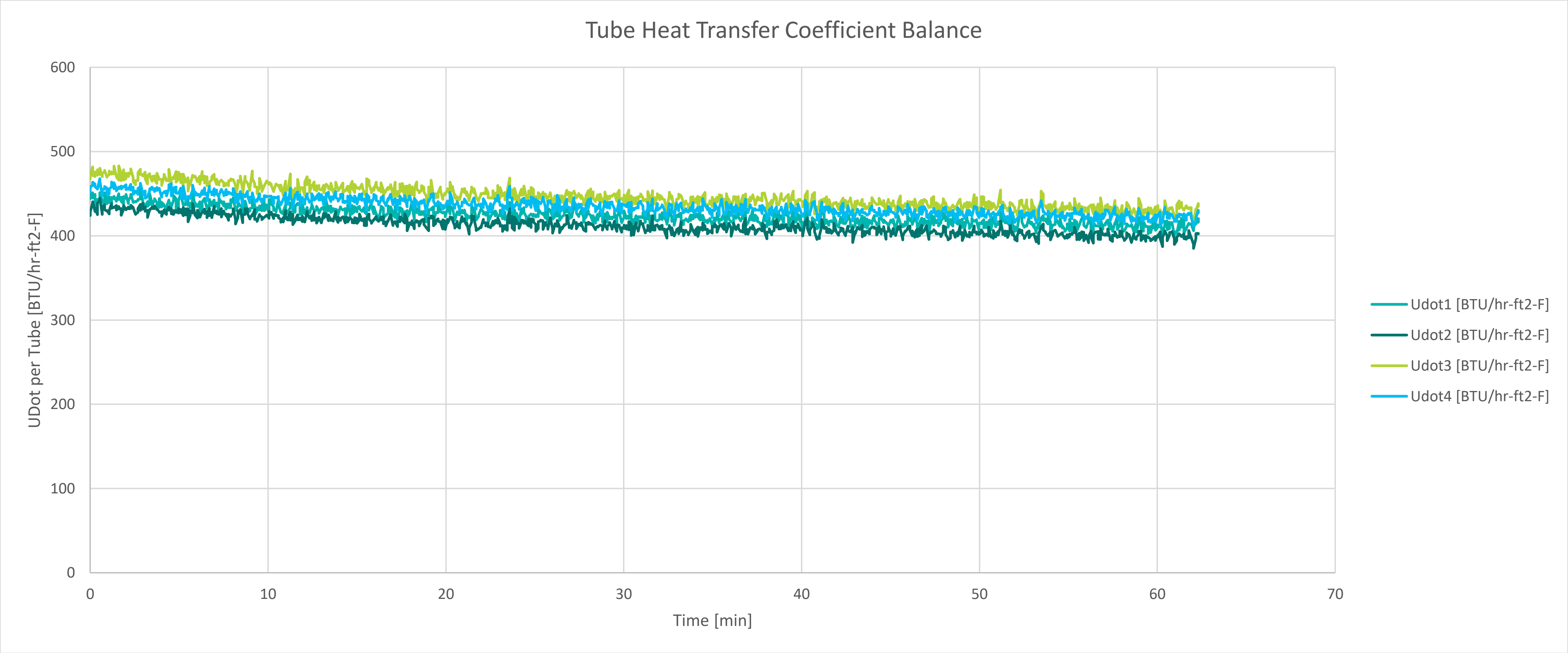
Test #1: Epoxy-based coating with additive

- Initial test run
- Tube 3 was untreated



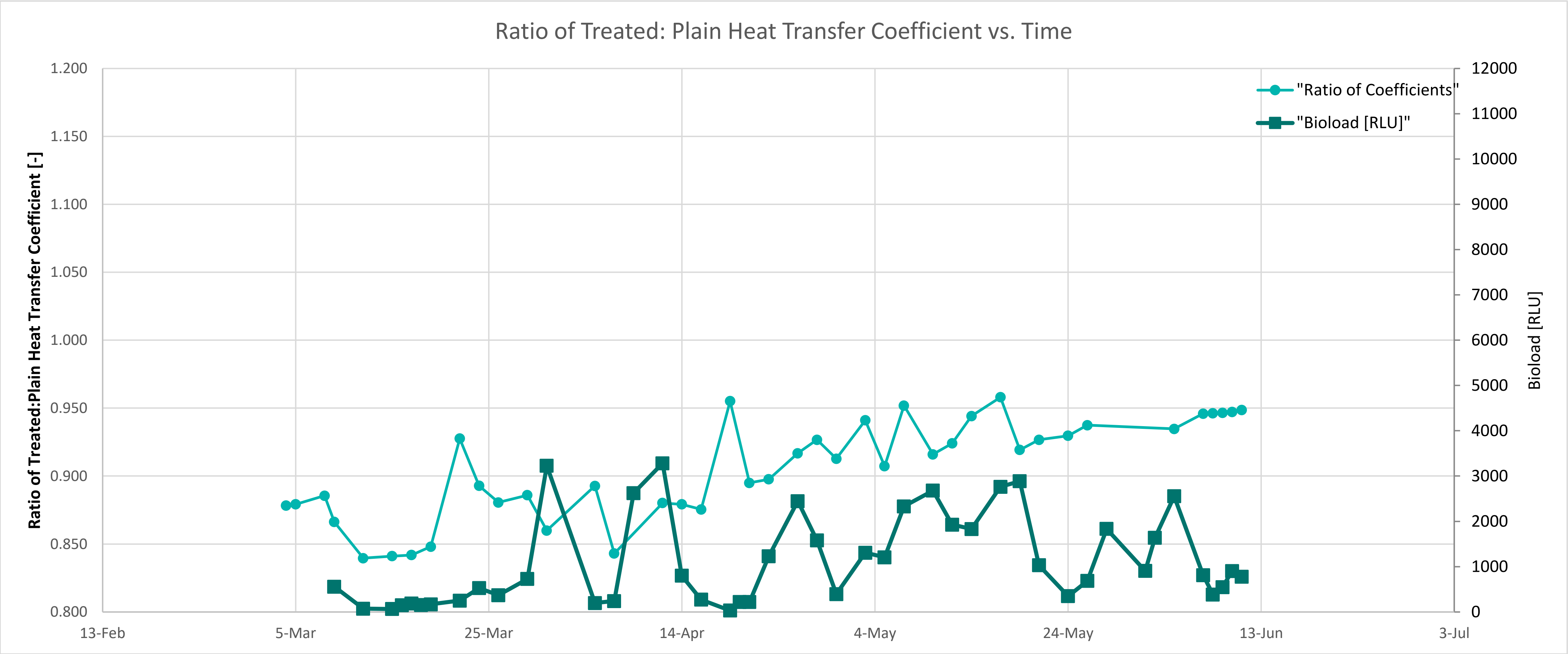
Test #1: Epoxy-based coating with additive

- Final test run
- Tube 3 was untreated



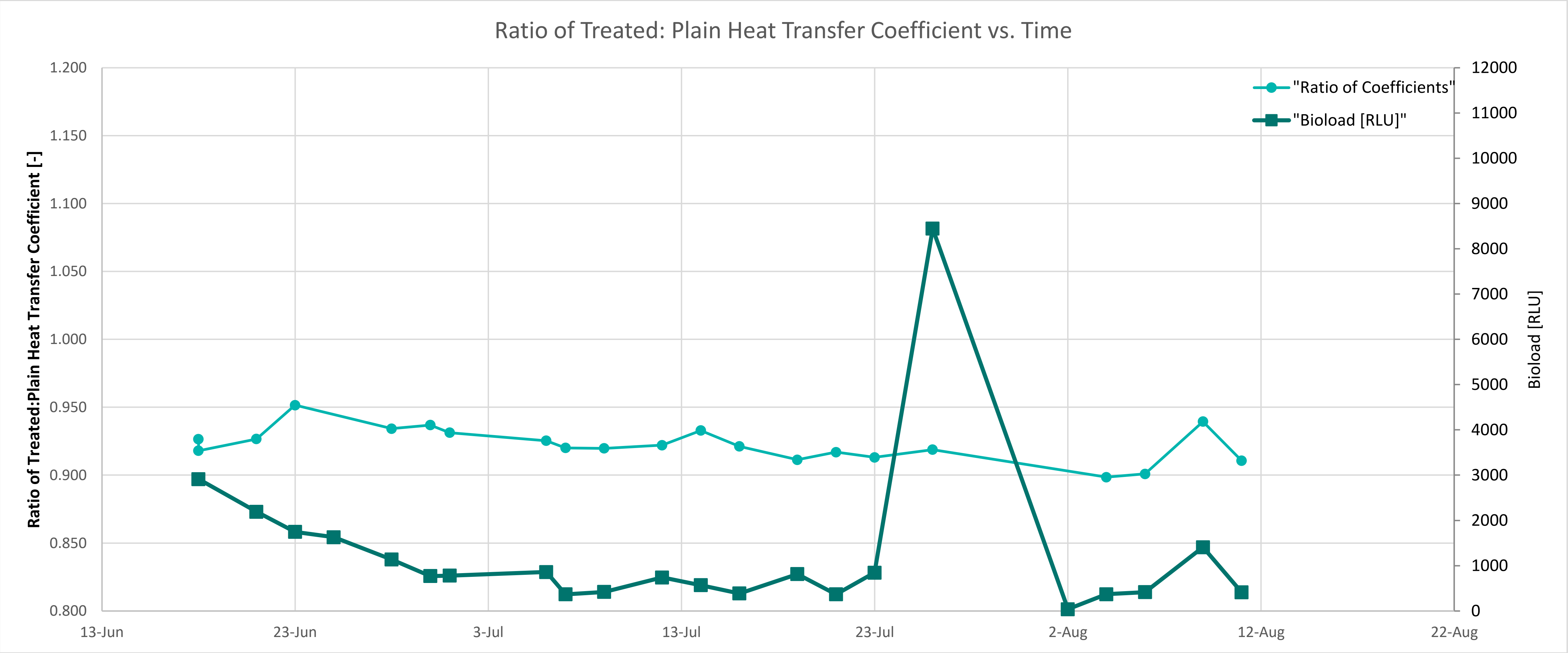
Test #1: Epoxy-based coating with additive

Changes in heat transfer coefficients over time



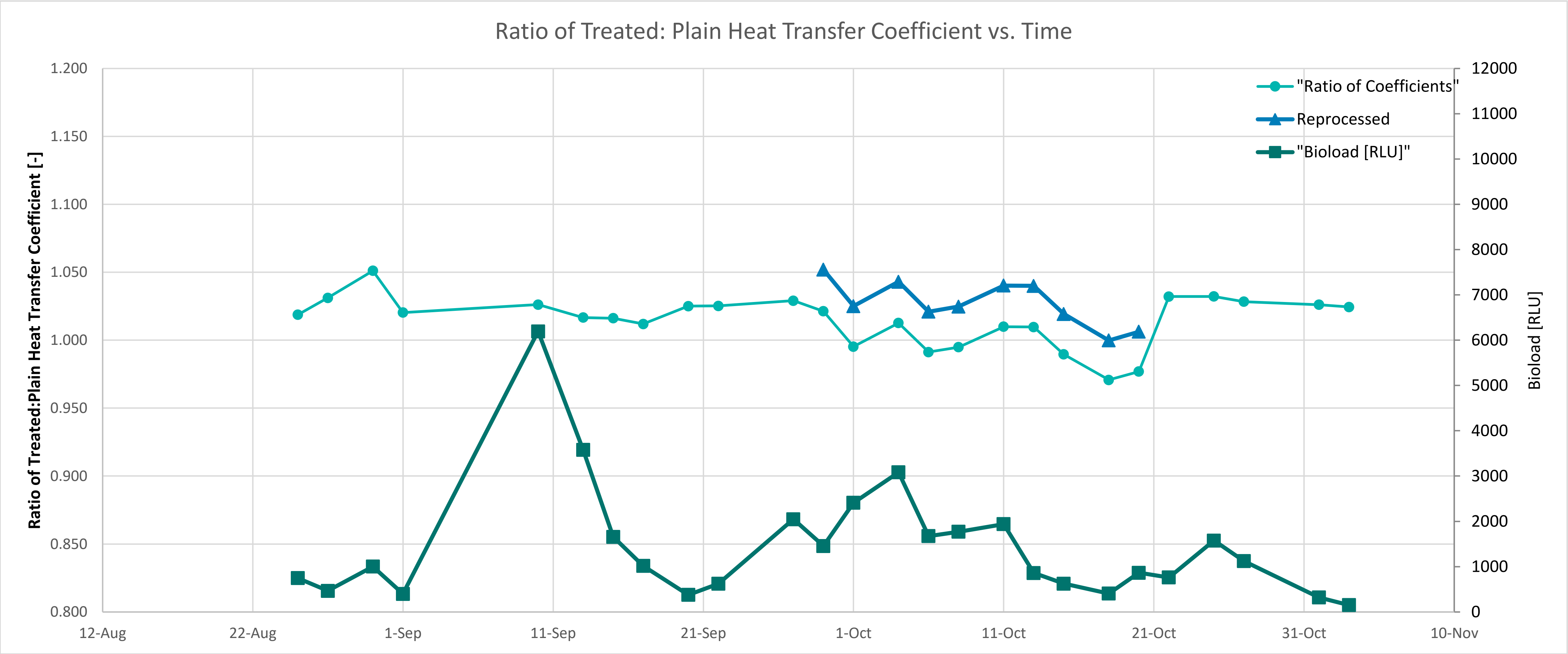
Test #2: Epoxy-based coating with nanocomposite

Changes in heat transfer coefficients over time

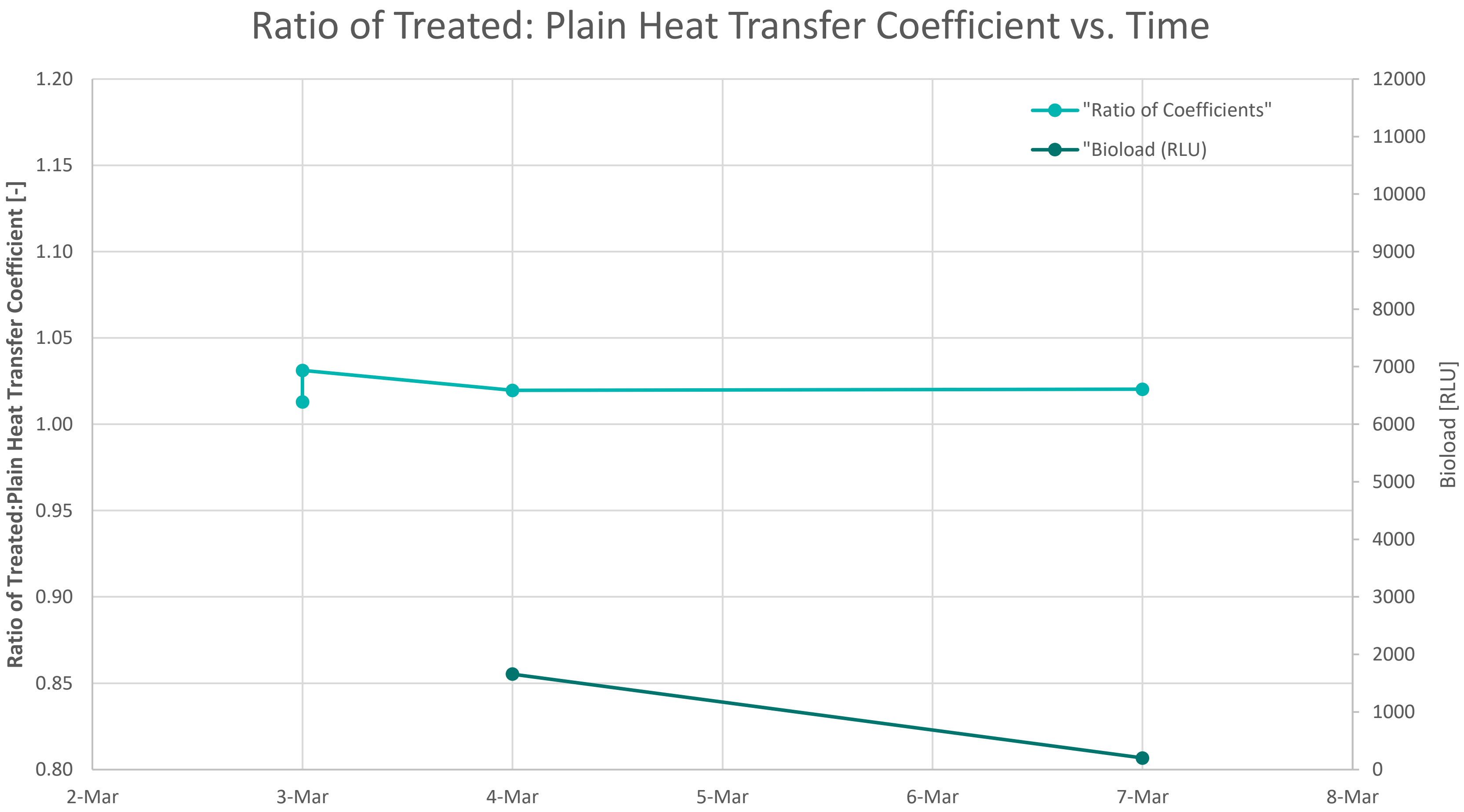


Test #3: Nano surface treatment

Changes in heat transfer coefficients over time

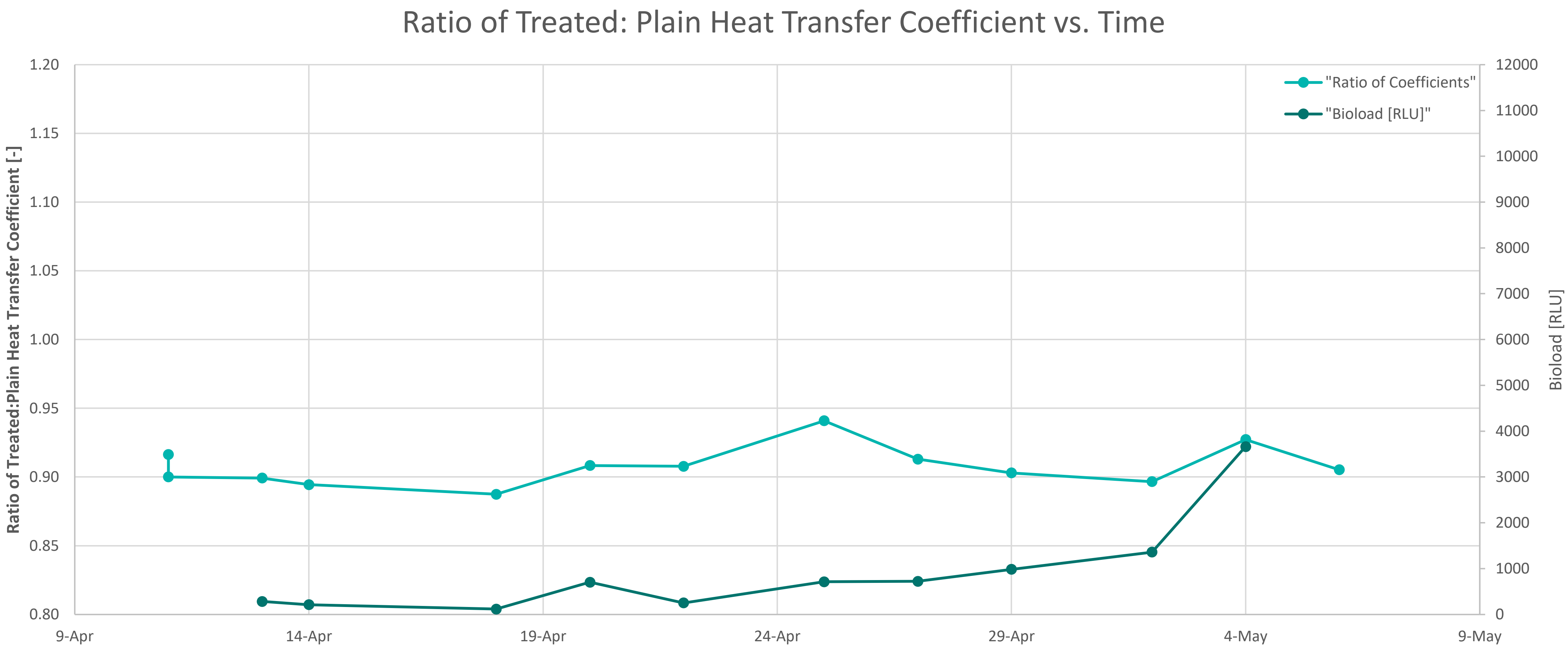


Test #4: Functionally Graded Superhydrophobic Coating



Test #5: Thin-Film Nanocomposite

Changes in heat transfer coefficients over time



External Treatments to Promote Condensate Shedding

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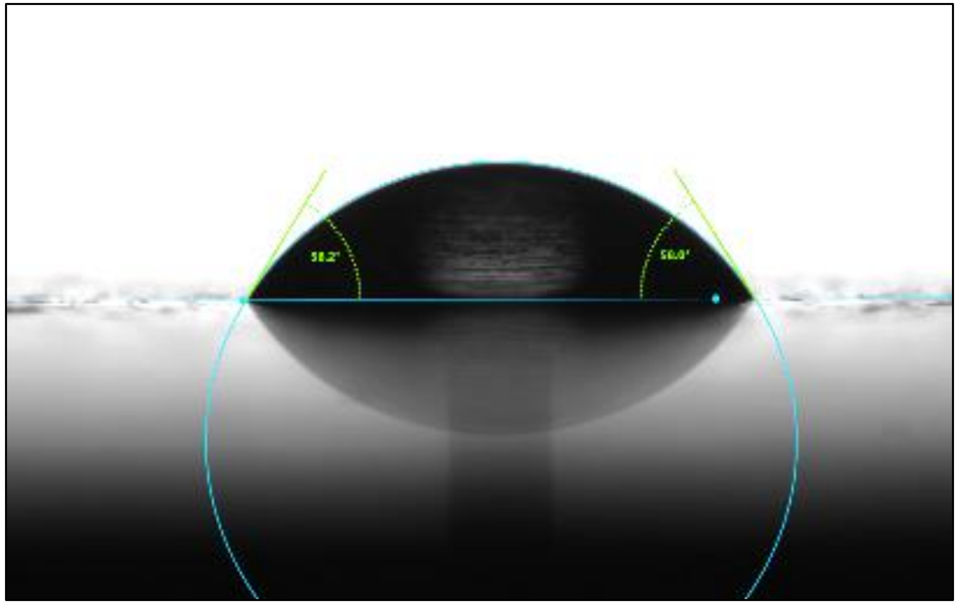
Hydrophobicity Testing

as-received coupon



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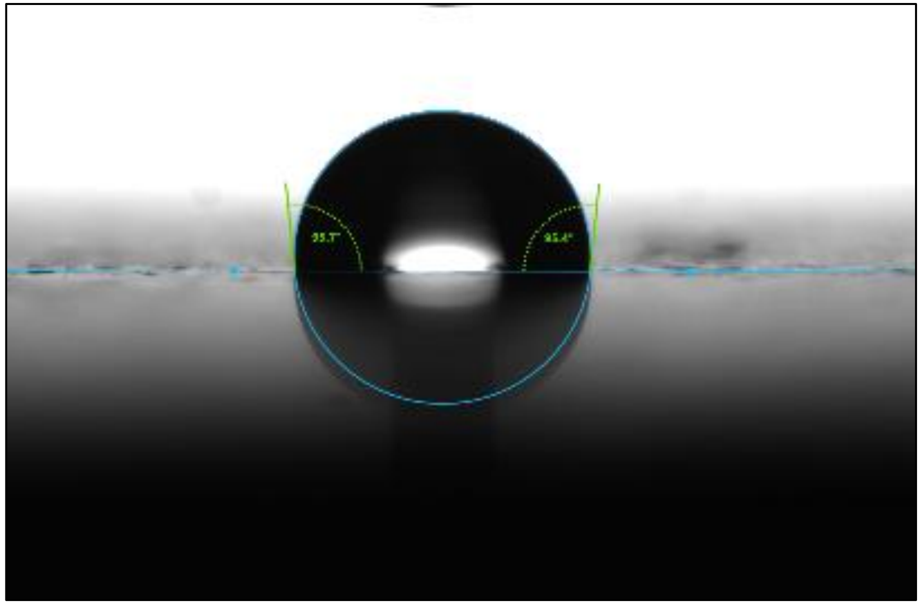


Hydrophobicity Test Conditions

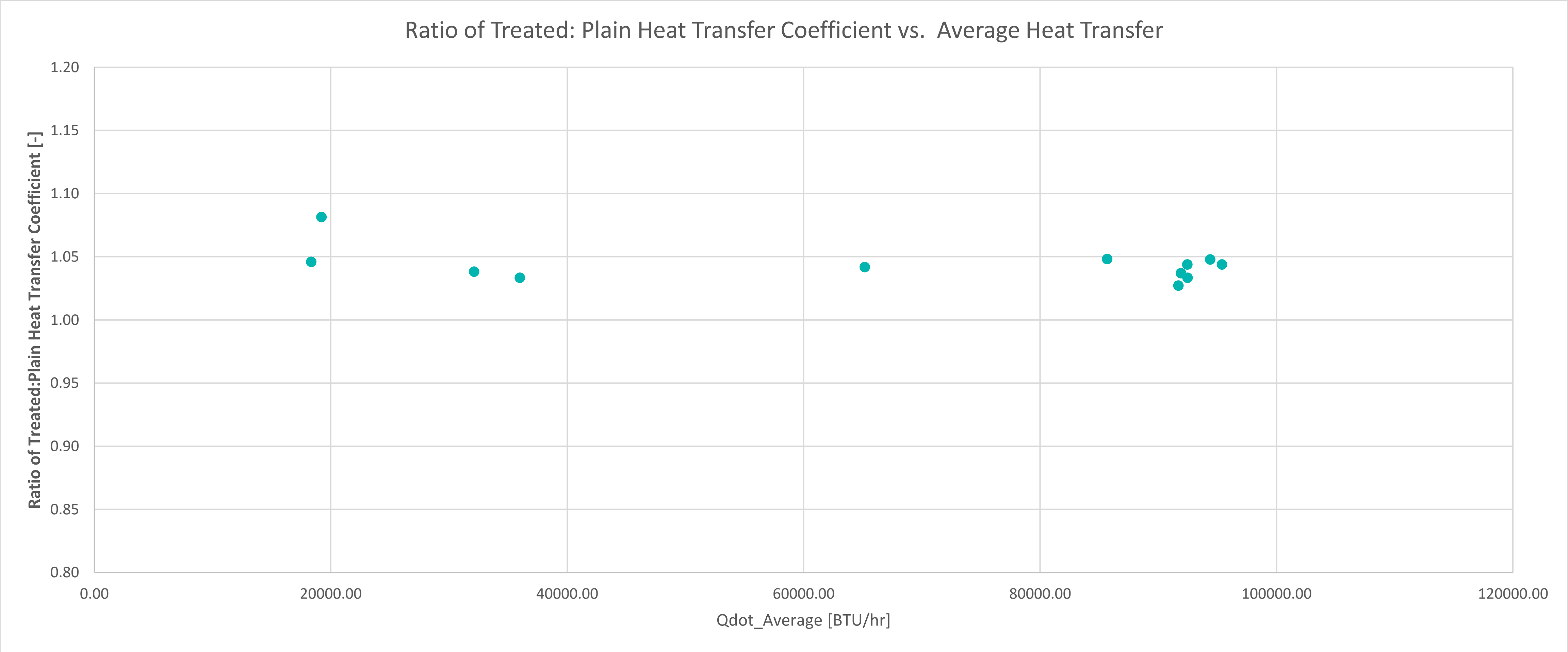
- Testing of external treatments looks for variations in performance at many operating conditions
  - Looks at ratio of heat transfer coefficients between treated and plain tubes
  - Over 1.0 means the treatments are outperforming a plain tube
  - Under 1.0 means the plain tube is outperforming the treated
  - May operate over extended time to test durability
  - Uses a test matrix which compares hydrophobicity at many heat flux conditions
- Conditions to prevent biofilm formation:
  - Standard biocide feed

Test Matrix

Cooling Water Flowrate (gpm)	Differential Temperature (^oF)
55	10
55	5
55	3
25	15
30	10
30	5

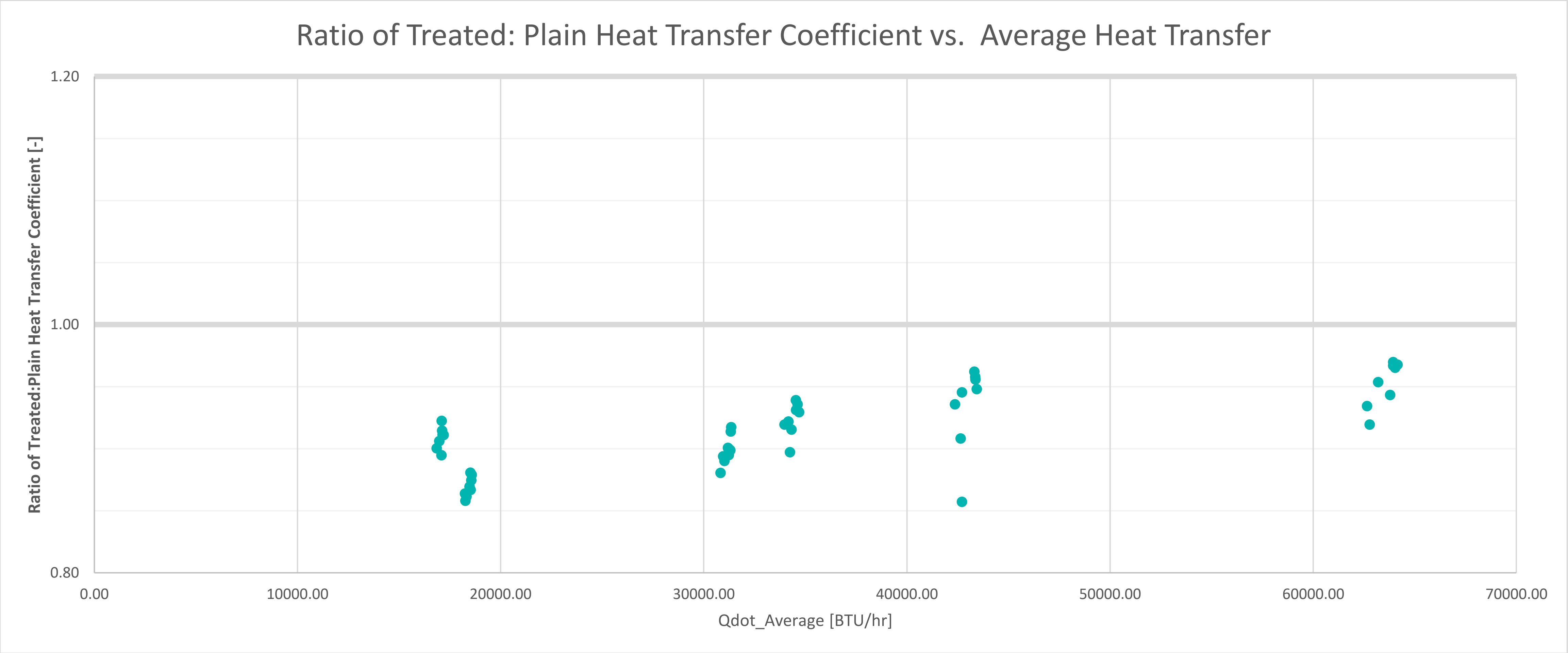
External Test #1: External Microtexture

- Changes in heat transfer by heat transfer rate

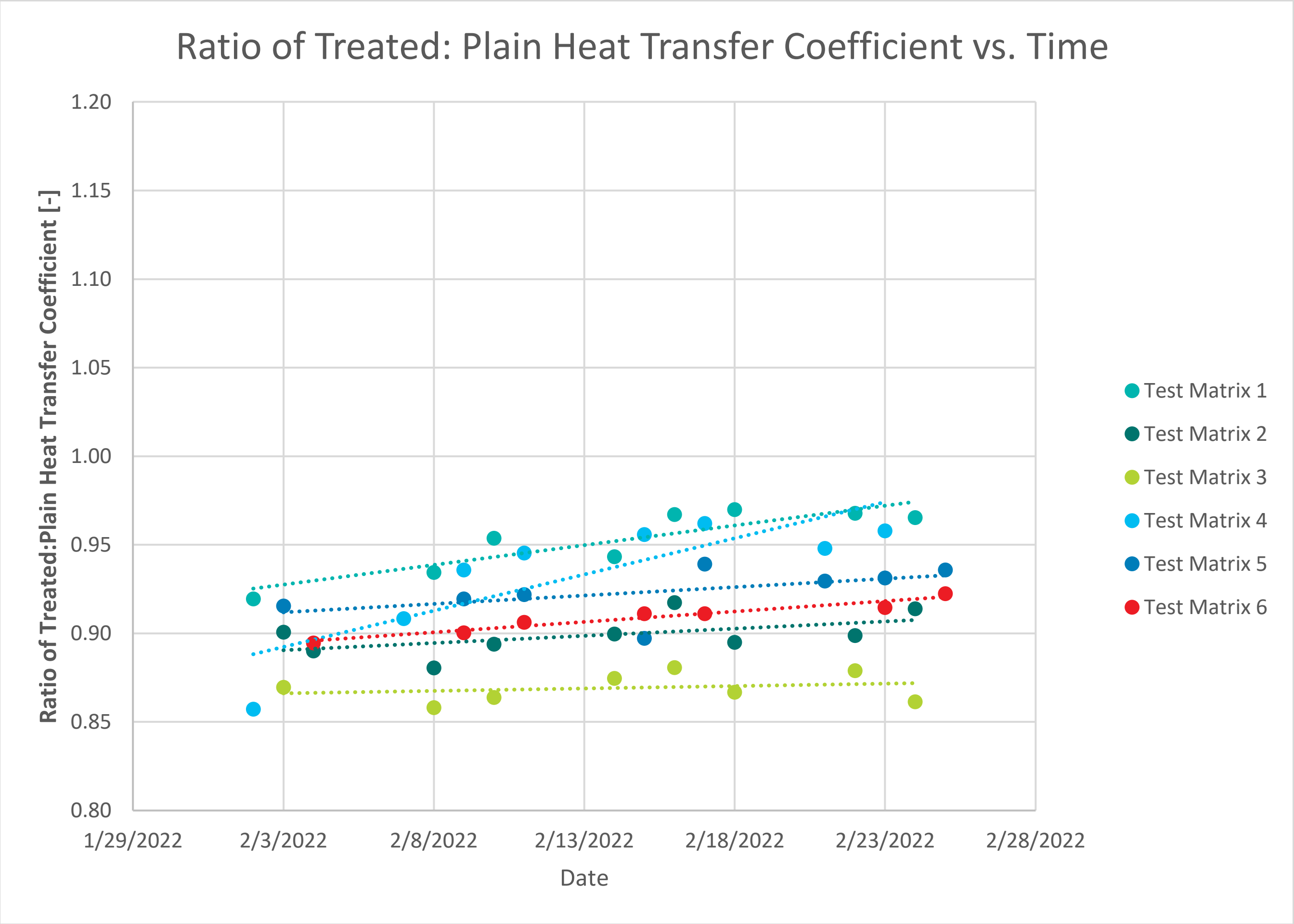


External Test #2: Functionally Graded Superhydrophobic Coating

- Changes in heat transfer by heat transfer rate

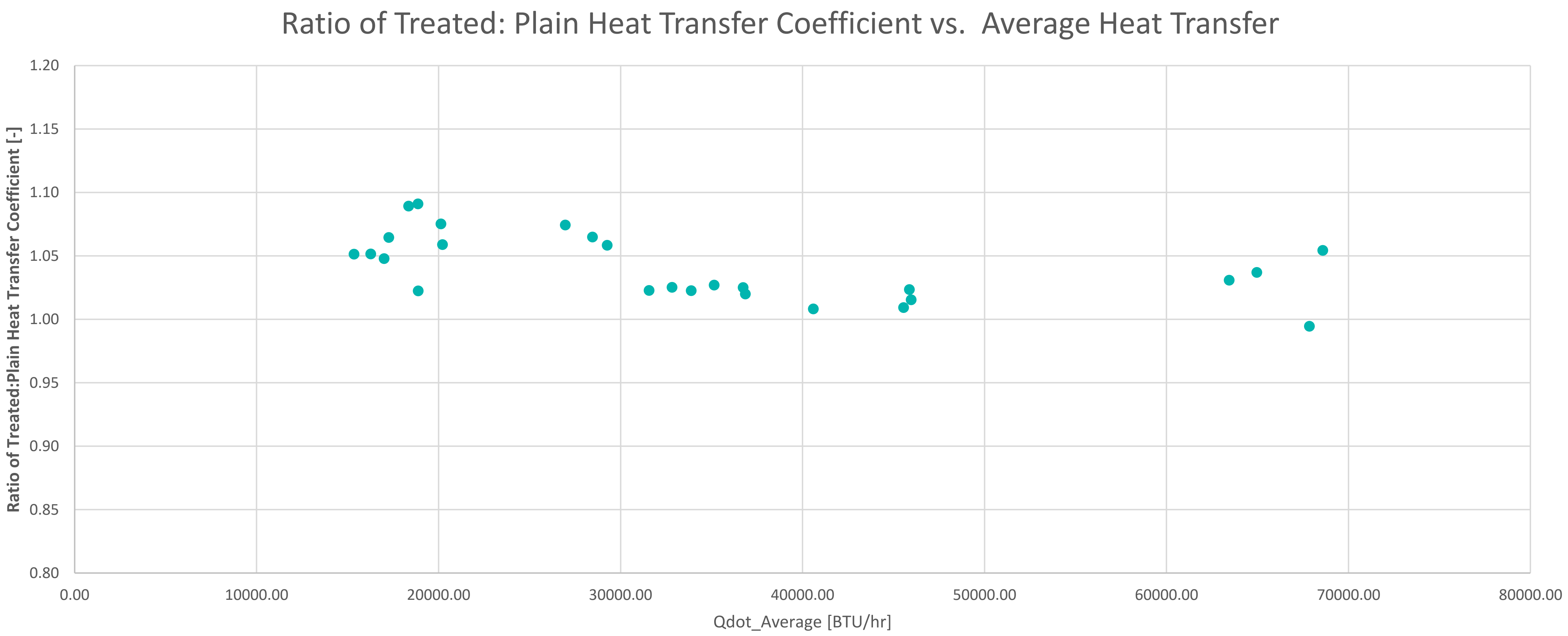


External Test #2: Functionally Graded Superhydrophobic Coating



External Test #3: Fluoro-Molecular Surface Treatment

Changes in heat transfer by heat transfer rate



Conclusions

- The test condenser at EPRI's Water Research and Conservation Center has provided consistent results for heat transfer measurement in a simulated power plant condenser environment.
- A variety of heat transfer testing scenarios for tube-and-shell heat exchangers can be evaluated with the test condenser and potentially other equipment at the WRCC.

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