Improved Quench Tank Performance and Part Quality Through CFD Analysis

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Quenching is a critical part of heat treatment

Quench agitation systems have not necessarily been designed for uniform treatment of the parts

Improvements to these systems would represent a significant improvement in part quality

Most effective approach is to modify the installed base

An effective tool is needed to assess potential changes
Use CFD to investigate design options

Focus on isothermal convection – better flow uniformity should lead to more uniform quenching through all three stages of the quench.

Approach

Film Boiling	Nucleate Boiling	Convection
Quench Tank Geometry

Base Case

- Draft tubes
- Support beams
- Deflector vanes
- Generic load
Velocity Distribution
Base Case

Deflector vanes create localized jets of flow

A portion of the flow bypasses the load entirely

Presence of support beams creates low velocity areas
Heat Transfer Coefficient Distribution

Base Case

“Shadows” from support beams create low heat transfer areas

Vanes cause front side of parts to have higher heat transfer than rear
Quench Tank Geometry

Option 1 – Add Flow Baffles

Prevent flow bypass

Channel flow through load
Velocity Distribution

Option 1 – Add Flow Baffles

Average velocity through load is increased (no bypass)

Effect of vanes and beams still present
Heat Transfer Coefficient Distribution

Option 1 – Add Flow Baffles

Peak heat transfer rates are increased over base case

Pattern remains largely unchanged
How good can it get?

CFD allows for the exploration of idealized cases that are not necessarily practical.

Quick and easy on the computer – difficult to try things out in hardware.

Overall flow concept is to bring flow in from bottom.

Try an idealized version of that concept to see if it works.
Quench Tank Geometry

Option 1 - Idealized Flow Entrance

External flow loop presents uniform flow to load

Not practical as a retrofit or even a new design
Velocity Distribution
Option 2 – Idealized Flow Entrance

Good front to back flow uniformity

Presence of support beams prevents better uniformity
Heat Transfer Coefficient Distribution

Option 2 – Idealized flow entrance

Lower overall heat transfer rates than baseline

Good front to back uniformity

Flow around beams creates high and low heat transfer zones
Quench Tank Geometry
Option 3 – Revised Support Structure

Egg crate support structure allows flow to pass through 1/2” web, 6” spacing, 12” tall.

16% flow blockage compared to 32% for beams.

Flow baffles omitted for clarity.

Egg crate support structure allows flow to pass through 1/2” web, 6” spacing, 12” tall.
Velocity Distribution
Option 3 – Bottom Inlet, Egg-Crate Support Structure

Very uniform flow throughout the load
Heat Transfer Coefficient Distribution

Option 3 – Bottom inlet, egg-crate support structure

Lower overall heat transfer coefficient

Very good uniformity
Quench Tank Geometry
Option 4 Design

Modified flow baffles channel flow beneath support structure

“Ladder” vanes distribute and turn flow up into the load
Ladder Vane Detail

Evenly spaced vanes along diagonal of 90 degree elbow evenly splits and turns flow

Requires even incoming flow
Velocity Distribution
Option 4 – Final Design

Spacing of ladder vanes matches spacing of egg-crate support.

Good flow uniformity
Heat Transfer Coefficient Distribution
Option 4 - Final Design

Good part to part uniformity

Good front to back uniformity

Higher heat transfer coefficient on bottom than on top

Overall heat transfer coefficient slightly less than baseline
Comparison of Cases

Distribution of Heat Transfer Coefficients

- Base Design
- With Shroud
- Uniform Bottom Inlet
- Uniform Bottom Inlet - Grid Support
- With Shroud, Grid Support, Ladder Vanes

Area (m²)

Local Convective Heat Transfer Coefficient (W/m²/K)
# Comparison of Cases

## Heat Transfer Coefficient Statistics

(W/m\(^2\)/K)

<table>
<thead>
<tr>
<th>Case</th>
<th>Min Value</th>
<th>Average Value</th>
<th>Max Value</th>
<th>Standard Deviation (% of mean)</th>
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<tbody>
<tr>
<td>Baseline</td>
<td>758</td>
<td>5896</td>
<td>18996</td>
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<tr>
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<tr>
<td>Option 4</td>
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<td>5259</td>
<td>12604</td>
<td>31.7%</td>
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</tbody>
</table>
Summary

Four alternatives to initial quench tank design were investigated.

Final design had:

- 11% reduced overall heat transfer coefficient
- 33% reduced variation in heat transfer coefficient

Baffles and flow control devices require 2.7 times as much pumping power (6 → 15.7 HP).

Overall quench rate could be increased by increasing quench flow rate.

Modifications could be incorporated in existing quench tank.
Questions?