ENERGY STAR
Commercial Dishwasher Test Method Webinar

January 25, 2012

Christopher Kent, U.S. Environmental Protection Agency
Ashley Armstrong, U.S. Department of Energy

ENERGY STAR Program
Agenda

- Introduction
- Validation Testing Overview
- Test Method
  - Definitions
  - Idle Energy Test
  - Flight Type
  - Post-sanitizing Rinse
  - Calculations
- Timeline
- Additional Information
  - Definition Revisions
  - Calculations
  - Test Data
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Webinar Goals

- Provide validation testing overview
- Discuss proposed changes to referenced test methods
- Discuss other test method issues
EPA–DOE Memorandum of Understanding (MOU)

- On September 30, 2009, EPA and DOE signed a memorandum of understanding (MOU) designed to enhance and strengthen the ENERGY STAR program

<table>
<thead>
<tr>
<th>EPA: Brand Manager</th>
<th>DOE: Technical Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>• New Products</td>
<td>• Test Methods</td>
</tr>
<tr>
<td>• Performance Levels</td>
<td>• Metrics</td>
</tr>
<tr>
<td>• Marketing &amp; Outreach</td>
<td>• Monitoring &amp; Verification</td>
</tr>
<tr>
<td>• Product Database</td>
<td></td>
</tr>
<tr>
<td>• Monitoring &amp; Verification</td>
<td></td>
</tr>
</tbody>
</table>
EPA-DOE ENERGY STAR Team

• As part of the MOU, DOE is the lead for writing and updating ENERGY STAR test methods
• Navigant is contracted by DOE to write new test methods and validate and/or update existing test methods
• DOE team will provide overview of support and findings related to the test method
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Test Method Validation

• DOE conducted testing to validate:

<table>
<thead>
<tr>
<th>Standard Test Method for Performance of Single-Rack, Door-Type Commercial Dishwashing Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Test Method for Performance of Rack Conveyor, Commercial Dishwashing Machines</td>
</tr>
<tr>
<td>Final Rinse Water Consumption</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ASTM F1696-07</th>
<th>ASTM F1920-11</th>
<th>ENERGY STAR Draft 1 Test Method (Rev. May 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Test Method for Performance of Single-Rack, Door-Type Commercial Dishwashing Machines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Test Method for Performance of Rack Conveyor, Commercial Dishwashing Machines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Rinse Water Consumption</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Test Method Validation

• Testing conducted at NSF International in Ann Arbor, MI

• Testing scope:
  – Idle energy rate (i.e. power) consumption
  – Rinse water consumption

• Evaluated issues that arose during testing

• Resolutions incorporated into ENERGY STAR Commercial Dishwashers Draft Test Method (Rev. Jan-2012)
## Test Method Scope

<table>
<thead>
<tr>
<th>Types</th>
<th>Tested</th>
<th>Not Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Under Counter</td>
<td>Flight Type</td>
</tr>
<tr>
<td></td>
<td>Single Tank, Door Type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single Tank Conveyor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple Tank Conveyor</td>
<td></td>
</tr>
<tr>
<td>Sub Types</td>
<td>Glasswashing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pot, Pan, and Utensil Washer</td>
<td></td>
</tr>
<tr>
<td>Rinse</td>
<td>Pumped</td>
<td>Post-sanitizing Rinse</td>
</tr>
<tr>
<td></td>
<td>Fresh Water</td>
<td></td>
</tr>
<tr>
<td>Tank Heat Type</td>
<td>Electric</td>
<td>Steam Injection</td>
</tr>
<tr>
<td></td>
<td>Gas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steam Coil</td>
<td></td>
</tr>
</tbody>
</table>
# Units Tested

<table>
<thead>
<tr>
<th></th>
<th>Tank Temperature</th>
<th>Tank Heat Type</th>
<th>Subcategory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Undercounter</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Electric</td>
<td>Glasswashing</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Electric</td>
<td>Chemical Dump Type</td>
</tr>
<tr>
<td><strong>Stationary Single Tank Door Type</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Electric</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Convertible</td>
<td>Gas</td>
<td>Dual Rated as Pot, Pan, Utensil</td>
</tr>
<tr>
<td><strong>Single Tank Conveyor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Steam</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Electric</td>
<td>--</td>
</tr>
<tr>
<td><strong>Multiple Tank Conveyor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Convertible</td>
<td>Electric</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Electric</td>
<td>--</td>
</tr>
</tbody>
</table>
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Definitions - Changes

- “Final” removed from “Final sanitizing Rinse” to include Post-sanitizing Rinse
- Mode Definitions
  - Wash, Rinse, and Dwell Modes
    - For stationary rack machines only
  - Idle Energy Mode
    - Added “ready to wash dishes at the required temperature”
  - Energy Saver Mode:
    - “A dishwasher is in energy saver mode if, after inactivity, the dishwasher converts to a setting that consumes less energy than it does in idle mode (not all dishwashers include this feature).”
Definitions - New Terms

- Water heater
- Booster heater
- Sanitization
- Sanitizing Solution
- Washing
- Fresh Water
- Sanitizing Rinse
- Chemical Sanitizing Rinse
- Hot Water Sanitizing Rinse
- Pumped Rinse
- Auxiliary Rinse
- Recirculating Sanitizing Rinse
- Non-recirculating Pumped Sanitizing Rinse
- Post-sanitizing Rinse
- Prewashing Unit
- Rack
- Ambient Temperature
- Flow Pressure
- Line Pressure
- Rated Temperature
- Tank Heater Idle Rate
- Uncertainty
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Maximum Energy Input Rate

- ASTM tests
  - Did not ensure dishwasher operating within 5% of manufacturer specified input rate
  - Overly burdensome

- ENERGY STAR proposed revisions:
  - No required starting temperature
  - More detailed test steps
  - Specific directions for:
    - Electric
    - Gas
    - Steam coil
# Booster Calibration

<table>
<thead>
<tr>
<th>Setting for units without recommended temperature</th>
<th>ASTM</th>
<th>ENERGY STAR (proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of 181°F</td>
<td></td>
<td>Minimum of 181°F</td>
</tr>
</tbody>
</table>

| Temperature verification                           | Average temperature verified over five cycles | Stabilized flowing rinse temperature greater than manufacturer specified temperature -1°F |
## Wash Tank Temperature

<table>
<thead>
<tr>
<th></th>
<th>ASTM</th>
<th>ENERGY STAR (proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature verified</td>
<td>Average</td>
<td>Minimum</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>None</td>
<td>15°F higher than minimum temperature</td>
</tr>
</tbody>
</table>
Idle Energy Measurement

- Account for differences between single and multiple tank machines
  - All tanks cycle twice before start of test
- Run longer than 3 hours if 10 cycles have not occurred
- Minimum temperature verified (instead of average)
- Maximum temperature limit: 15°F above manufacturer specified tank temperature
Internal Booster Heaters

• ASTM procedures are for external boosters
• Internal booster heater machines unfairly penalized if internal booster heat included in idle energy
• Sub-monitor or separately monitor internal booster heater idle energy
  – Similar to method for measuring tank heater idle energy
• Some internal booster heaters cannot physically be separately monitored
  – Include internal booster heat in idle energy
Energy Saver Mode

- Draft test method requires disabling Energy Saver Mode prior to testing
  - Ensures ENERGY STAR specifications achieved with most conservative set-up
  - Reward efficient Idle Mode designs
  - “As shipped” settings vary
    - Typical durations before Energy Saver Mode turns on
    - User ability to override or change setting
  - Energy to convert from:
    - Idle Mode to Wash Mode
    - Energy Saver Mode to Wash Mode
Steam Coil Test Method

• At inlet, record:
  – Steam Temperature
  – Steam Pressure
  – Steam Volumetric Flow Rate

• At outlet, record:
  – Water Temperature
  – Water Pressure

• Record at least every second
• Record time delay between inlet and outlet
• Confirm majority non-condensed steam used at inlet
Steam Coil Calculations

• For each data point:
  – Inlet Stream and Outlet Stream Enthalpies
    • Based on mass calculations and steam tables
  – Instantaneous Energy Consumption

• Total energy consumption:
  – Sum of:
    • Instantaneous energy consumption for each data point
    • Electric energy consumption
Steam Coil Test Method

• Is the test method generally applicable to all dishwashers with steam coil tank heat?
• What are typical ranges of steam “quality” (i.e. how much steam vs. water) of the inlet and outlet streams?
Steam Injection Test Method

- Steam injection unit not tested
- Test method not developed
- Test method would be similar to steam coil test method
  - Enthalpy of inlet stream measured
  - Steam injected directly into water
  - Outlet stream would be tank overflow?
  - Other energy losses?
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Flight Type Machines

- Conveyor test method applicable:
  - Water consumption
  - Idle energy

- Are any modifications to conveyor test method necessary to accommodate flight types?
Agenda

- Introduction
- Validation Testing Overview
- Test Method
  - Definitions
  - Idle Energy Test
  - Flight Type
  - Post-sanitizing Rinse
  - Calculations
- Timeline
- Additional Information
  - Definition Revisions
  - Calculations
  - Test Data
Post-sanitizing Rinse - Water Consumption

- Water from Post-sanitizing Rinse included in water consumption value
- Setup and verification for Post-sanitizing Rinse similar to Sanitizing Rinse
- Known design:
  - Stationary rack
  - Fresh Water
  - Same spray system for Sanitizing and Post-sanitizing Rinses
- Test methods developed for other possible designs
Post-sanitizing Rinse - Water Consumption

• Would machines with a fresh water Sanitizing Rinse always have a fresh water Post-sanitizing Rinse?
Post-sanitizing Rinse - Water Consumption

• Would machines with a fresh water Sanitizing Rinse always have a fresh water Post-sanitizing Rinse?
• Would machines with a pumped water Sanitizing Rinse always have a pumped water Post-sanitizing Rinse?
Post-sanitizing Rinse - Water Consumption

• Would machines with a fresh water Sanitizing Rinse always have a fresh water Post-sanitizing Rinse?
• Would machines with a pumped water Sanitizing Rinse always have a pumped water Post-sanitizing Rinse?
• Would fresh water Sanitizing Rinse Stationary Rack type machines always use the same spray system for the Sanitizing Rinse and Post-sanitizing Rinse?
Post-sanitizing Rinse - Water Consumption

- Would machines with a fresh water Sanitizing Rinse always have a fresh water Post-sanitizing Rinse?
- Would machines with a pumped water Sanitizing Rinse always have a pumped water Post-sanitizing Rinse?
- Would fresh water Sanitizing Rinse Stationary Rack type machines always use the same spray system for the Sanitizing Rinse and Post-sanitizing Rinse?
- For conveyor machines, would the Post-sanitizing Rinse always have a solenoid for activation?
Post-sanitizing Rinse - Idle Energy

• Post-sanitizing Rinse feature does not consume idle energy
• No modifications to idle energy test necessary to accommodate Post-Sanitizing Rinse
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Calculations

- **Racks per Hour**
  - NSF Metric
  - Truncated to next lowest whole number

- **Gallons per Hour**
  - NSF Metric
  - Includes number of racks for stationary type machines

- **Gallons per Rack**
  - ENERGY STAR Metric
Stakeholder Discussion

• Other questions or comments?
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
## Version 2.0 Revision Timeline

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 9, 2012</td>
<td>Draft Test Method Published</td>
</tr>
<tr>
<td>January 25, 2012</td>
<td><strong>Test Method Webinar</strong></td>
</tr>
<tr>
<td>January 30, 2012</td>
<td>Stakeholder Comments Due</td>
</tr>
<tr>
<td>February 2012</td>
<td>Final Draft Specification Published</td>
</tr>
<tr>
<td><strong>March 2012</strong></td>
<td>Draft 2 or Final Draft Test Method Published*</td>
</tr>
<tr>
<td></td>
<td>Final Version 2.0 Specification Published with Final Test Method</td>
</tr>
<tr>
<td><strong>December 2012</strong></td>
<td>Version 2.0 Specification Effective</td>
</tr>
</tbody>
</table>

* Pending need for additional drafts
Contact Information

Please send any additional comments to commercialdishwashers@energystar.gov or contact:

Christopher Kent  
EPA ENERGY STAR Program  
Kent.Christopher@epa.gov

Becky Duff  
ICF International  
RDuff@icfi.com

Ashley Armstrong  
DOE ENERGY STAR Program  
Ashley.Armstrong@ee.doe.gov

Julie Pierce  
Navigant Consulting, Inc.  
Julie.Pierce@navigant.com
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Definition Revisions

- **Single Tank, Door Type:** A stationary rack machine designed to accept a standard nominal 20 inch x 20 inch dish rack which requires the raising of a door to place the rack into the wash/rinse chamber. Closing of the door typically initiates the wash cycle. Subcategories of single tank, stationary door type machines include: single rack, double rack, pot, pan and utensil washers, chemical dump type and hooded wash compartment (“hood type”). Single tank, door type models can be either chemical or hot water sanitizing, with an internal or external booster heater for the latter.
• **Single Tank Conveyor**: A conveyor machine that includes a tank for wash water followed by a final sanitizing rinse. This type of machine does not have a pumped rinse tank. This type of machine may include a prewashing section ahead of the washing section and an auxiliary rinse section for purposes of reusing the sanitizing final rinse water between the power rinse and sanitizing final rinse sections. Single tank conveyor dishwashers can be either chemical or hot water sanitizing, with an internal or external booster heater for the latter.
Definition Revisions

- **Multiple Tank Conveyor**: A conveyor type machine that includes one or more tanks for wash water and one or more tanks for pumped rinse water, followed by a final sanitizing rinse. This type of machine may include a pre-washing section before the washing section and an auxiliary rinse section for purposes of reusing the sanitizing rinse water between the power rinse and final sanitizing rinse section. Multiple tank conveyor dishwashers can be either chemical or hot water sanitizing, with an internal or external booster heater for the latter.
Definition Revisions

- **Chemical Dump Type Machine**: A low temp, stationary rack machine with a pumped recirculated final sanitizing rinse.

- **Product Family**: Variations of one model offered within a single product line with design differences limited to: finish/color; length of pre-wash section, voltage, and orientation (e.g., corner, straight through models). Individual models represented by a product family must have the same final sanitizing and post-sanitizing rinse water and idle energy consumption.
Definition Revisions

- **Wash Mode**: For stationary rack machines, the dishwasher is in **wash mode** when it **Machine** is actively running a cycle and is spraying wash water (i.e., water that is neither part of the **final sanitizing rinse**, **post-sanitizing rinse**, nor the prewashing unit).

- **Rinse Mode**: For stationary rack machines, the dishwasher is in **rinse mode** when it **Machine** is at the end of the actively running cycle and is spraying final **hot water** or chemical **sanitizing rinse water** or a **post-sanitizing rinse**.

- **Dwell Mode**: For stationary rack type, the dishwasher is in **dwell mode** when it **machine** is actively running a cycle but is not in wash or rinse modes.
Definition Revisions

- **Idle Mode**: For all dishwasher types, the dishwasher is in idle mode when it machine is not actively running a cycle but is still powered on and ready to wash dishes at the required temperature.

- **Idle Energy Rate**: The rate of energy consumed by the dishwasher tank heater while “holding” or maintaining wash tank water at the thermostat(s) set point during the time period specified in ASTM Standards F1920-11 and F1696-07.

- **Energy Saver Mode**: A dishwasher is in energy saver mode if, after inactivity, the dishwasher converts to a setting that consumes less energy than it does in idle mode (not all dishwashers include this feature).
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
Calculations - Racks per Hour

- Fresh Water or Pumped Water Sanitizing or Post-Sanitizing Rinse Stationary Type Machines

\[
Racks \text{ per Hour} = \frac{3600 \text{ seconds} \times NR}{(WT + RT + DT + LT) \text{ (seconds)}}
\]

Where:

- Racks per Hour = Number of racks washed per hour, truncated to the next lowest whole number
- NR = Number of racks washed per cycle
- WT = Wash time (i.e. amount of time spent in wash mode) in seconds as recorded during test
- RT = Rinse time (i.e. amount of time spent in rinse mode, including a post-sanitizing rinse) in seconds as recorded during test
- DT = Dwell time (i.e. amount of time spent in dwell mode) in seconds as recorded during test
- LT = Load time (30 seconds for under counter Dishwashers, 5 seconds for straight through door-type Dishwashers, 7 seconds for corner door-type Dishwashers, 30 seconds for front load/unload door-type Dishwashers)
Calculations - Racks per Hour

- Fresh Water or Pumped Water Sanitizing or Post-Sanitizing Rinse Conveyor Type (excluding Flight Type) Machines

\[
\text{Racks per Hour} = \frac{\text{CS} \times \frac{60 \text{ minutes}}{\text{hour}}}{\text{RL} \times \frac{1 \text{ ft}}{12 \text{ in}}}
\]

Where:

- Racks per Hour = Number of racks washed per hour, truncated to the next lowest whole number
- RL = Rack length (use 20 inches)
- CS = Manufacturer specified maximum conveyor speed in feet per minute
Calculations - Gallons per Hour

- Fresh Water or Pumped Water Sanitizing or Post-Sanitizing Rinse Stationary Type Machines

\[
\text{Gallons per Hour} = \frac{\sum_{n=1}^{5} \frac{\text{Measured Weight of water for cycle } n \text{ (lbs)}}{8.34 \text{ lbs/gal}} \times \frac{\text{Racks per Hour}}{\text{NR}}}{\text{5 cycles}}
\]

Where:

- Racks per Hour = Number of racks washed per hour, truncated to the next lowest whole number, as calculated in Section 7.1
- NR = Number of racks washed per cycle
Calculations - Gallons per Hour

• Fresh Water or Pumped Water Sanitizing or Post-Sanitizing Rinse Conveyor Type (including Flight Type) Machines

\[
\text{Gallons per Hour} = \frac{\sum_{n=1}^{5} \text{ Measured Weight of water for test run } n \text{ (lbs)}}{\text{Rinse Activation Duration for test run } n \text{ (seconds)}} \times \frac{5 \text{ test runs} \times \frac{0.34 \text{ lbs}}{\text{gal}} \times \frac{1 \text{ hour}}{3600 \text{ seconds}}}{\text{gal}}
\]

Where:

• Measured Weight of water for test run \( n \) = Weight of water sent to capture vessel from one minute of sanitizing rinse and post-sanitizing rinse solenoid activation
• Rinse Activation Duration = Measured duration of sanitizing rinse and post-sanitizing rinse solenoid activation (one minute +/- one second)
Calculations - Water Consumption

• Fresh Water or Pumped Water Sanitizing or Post-Sanitizing Rinse Stationary Rack Type Machines

\[
\text{Gallons per Rack} = \frac{\text{Gallons per Hour}}{\text{Racks per Hour}}
\]

Where:

• Gallons per Hour = Water use in gallons per hour, as calculated in Section 7.2
• Racks per Hour = Number of racks washed per hour, truncated to the next lowest whole number, as calculated in Section 7.1
Calculations - Water Consumption

- Fresh Water or Pumped Water Sanitizing and Post-Sanitizing Rinse Conveyor Type (excluding Flight Type) Machines

\[
\text{Gallons per Rack} = \frac{\text{Gallons per Hour}}{\text{Racks per Hour}}
\]

Where:

- Gallons per Hour = Water use in gallons per hour, as calculated in Section 7.2
- Racks per Hour = Number of racks washed per hour, truncated to the next lowest whole number, as calculated in Section 7.1
Calculations - Water Consumption

• Pot, Pan, and Utensil Type Machines

\[
\text{Gallons per Square Foot} = \frac{\text{Gallons per Rack}}{\text{Square foot of rack}}
\]

Where:

• Gallons per Rack= Water use in gallons per hour, as calculated in Section 7.3A)
• Square foot of rack= Manufacturer specified rack area in ft\(^2\) for machine tested
Calculations - Steam Coil

• Inlet Steam Mass Flow Rate

  – Find the measured pressure and temperature values for the inlet stream for each data point in the superheated or saturated steam tables (depending on the state of the steam) and record the listed density ($\rho_{\text{steam}}$). If the exact pressure and temperature are not listed in the table, interpolate between the two closest pressure and temperature values to calculate the density.

  – Calculate the mass flow rate for each data point as follows:

    $$M_{\text{Steam}} = \dot{V}_{\text{Steam}} \times \rho_{\text{Steam}}$$

    Where:

    • $M_{\text{Steam}}$ = Mass flow rate of steam (pounds (lb)/h)
    • $\dot{V}_{\text{Steam}}$ = Measured volumetric flow rate of steam (ft$^3$/h)
    • $\rho_{\text{Steam}}$ = Density of steam (lb/ft$^3$), calculated from steam tables
Calculations - Steam Coil

• Inlet Steam Total Mass

\[ M_{\text{Total}} = \sum_{i=1}^{N} (M_{\text{Steam},i} \times t_i) \times \frac{1 \text{ hour}}{3600 \text{ seconds}} \]

Where:

• \( M_{\text{Total}} \) = Total steam consumption during time period (lb)
• \( M_{\text{Steam},i} \) = Instantaneous steam mass flow rate for each data point (lb/h)
• \( N \) = Total number of data points during time period, excluding extra data to account for \( t_{\text{delay}} \)
• \( t_i \) = Time interval of each data point (seconds)
Calculations - Steam Coil

• Inlet Stream Enthalpy

  – Find the measured pressure and temperature values for the inlet steam for each data point in the superheated or saturated steam tables (depending on the state of the steam) and record the listed enthalpy ($H_{\text{Inlet}}$). If the exact pressure and temperature are not listed in the table, interpolate between the two closest pressure and temperature values to calculate the enthalpy.
Calculations - Steam Coil

- Outlet Water Enthalpy

  - Find the pressure value for the outlet water for each data point in the saturated steam tables. Record the listed saturated liquid enthalpy value ($H_{\text{Saturated}}$) and saturated temperature value ($T_{\text{Saturated}}$). If the exact pressure is not listed in the table, interpolate between the two closest pressure values to calculate the enthalpy.

  - Calculate the enthalpy of the outlet water for each data point as follows:

    $$H_{\text{Outlet}} = H_{\text{Saturated}} - (C_p \times (T_{\text{Saturated}} - T_{\text{Measured}}))$$

Where:

- $H_{\text{Outlet}}$ = Enthalpy of Dishwasher outlet stream (British thermal units (Btu)/lb)
- $H_{\text{Saturated}}$ = Saturated liquid enthalpy value listed in steam tables (Btu/lb)
- $C_p$ = Heat capacity of water (1 Btu/lb °F)
- $T_{\text{Saturated}}$ = Saturated liquid temperature value listed in steam tables (°F)
- $T_{\text{Measured}}$ = Recorded temperature of liquid water outlet stream during test (°F)
Calculations - Steam Coil

• Instantaneous Energy Consumption

  – Calculate the energy for each data point as follows:

  \[ E_t = M_{\text{steam}} \times (H_{\text{inlet}} - H_{\text{outlet} + \text{delay}}) \times t_t \times \frac{1}{3600 \text{ seconds}} \]

  Where:

  • \( E_t \) = Instantaneous energy consumption for each data point (Btu)
  • \( M_{\text{steam}} \) = Calculated mass flow rate of steam for each data point (lb/h)
  • \( H_{\text{inlet}} \) = Enthalpy of Dishwasher inlet steam for each data point (Btu/lb)
  • \( H_{\text{outlet} + \text{delay}} \) = Enthalpy of Dishwasher outlet water for each data point (Btu/lb)
  • \( t_{\text{delay}} \) = Measured time between steam entering the flow meter and exiting as water (seconds)
  • \( t_t \) = Time interval of each data point (seconds)
Calculations - Steam Coil

- Total Energy Consumption

\[ E_{\text{Total}} = \sum_{i=1}^{N} (E_i) + E_{\text{Electric}} \]

Where:

- \( E_{\text{Total}} \) = Total energy consumption during test (active or idle) (Btu)
- \( E_i \) = Instantaneous energy consumption for each data point (Btu)
- \( E_{\text{Electric}} \) = Electric energy consumption during test (Btu)
- \( N \) = Total number of data points, excluding extra data to account for \( t_{\text{delay}} \)
Agenda

• Introduction
• Validation Testing Overview
• Test Method
  – Definitions
  – Idle Energy Test
  – Flight Type
  – Post-sanitizing Rinse
  – Calculations
• Timeline
• Additional Information
  – Definition Revisions
  – Calculations
  – Test Data
## Test Unit Summary

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Unit Number</th>
<th>Test Type</th>
<th>Machine Type</th>
<th>Tank Temperature</th>
<th>Tank Heat Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Initial</td>
<td>Undercounter</td>
<td>Low</td>
<td>Electric</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Initial</td>
<td>Undercounter</td>
<td>High</td>
<td>Electric</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Initial</td>
<td>Door Type</td>
<td>High</td>
<td>Gas</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>Alternate Temperature</td>
<td>Door Type</td>
<td>Low</td>
<td>Gas</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>Initial</td>
<td>Door Type</td>
<td>High</td>
<td>Electric</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Repeatability</td>
<td>Door Type</td>
<td>High</td>
<td>Electric</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>Repeatability</td>
<td>Door Type</td>
<td>High</td>
<td>Electric</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>Initial</td>
<td>Single Tank Conveyor</td>
<td>Low</td>
<td>Electric</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>Repeatability</td>
<td>Single Tank Conveyor</td>
<td>Low</td>
<td>Electric</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>Repeatability</td>
<td>Single Tank Conveyor</td>
<td>Low</td>
<td>Electric</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>Initial</td>
<td>Single Tank Conveyor</td>
<td>High</td>
<td>Steam</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>Initial</td>
<td>Multiple Tank Conveyor</td>
<td>High</td>
<td>Electric</td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>Alternate Temperature</td>
<td>Multiple Tank Conveyor</td>
<td>Low</td>
<td>Electric</td>
</tr>
<tr>
<td>14</td>
<td>8</td>
<td>Initial</td>
<td>Multiple Tank Conveyor</td>
<td>High</td>
<td>Electric</td>
</tr>
</tbody>
</table>
Validation Test Data Summary

- Measured Idle Energy and Rinse Water Consumption values are compared to:
  - Values listed in ENERGY STAR database (if applicable)
  - ENERGY STAR Commercial Dishwashers Version 1.2 Specification
Idle Energy Validation Test Data

![Graph showing the relationship between Idle Energy Rate (kW) and Test Number. The graph includes markers for ENERGY STAR Listed, Measured, and ENERGY STAR Upper Limit.](image-url)
Rinse Water Consumption Validation Test Data

![Graph showing water consumption data](image)

- **Energy Star Listed**
- **Measured**
- **Energy Star Upper Limit**

Test Number:
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15