# PTC 12.1 Calculations Using PEPSE – Beta Testing

by

Gene Minner – Curtiss Wright

Jerry Weber – Midwest Generation, EME

# Edison Mission Energy

- Coal Fired Capacity
  - 6 sites in Illinois – Midwest Generation
  - 1 site in Pennsylvania
  - 1 site in West Virginia
- Wind Capacity – 812 WTGs and growing
- Gas Fired -9 sites in California and Washington

# PTC 12.1

## Feedwater Heater Acceptance Testing

- Purpose – perform acceptance testing on new heaters or test existing heaters
- Conducted within 10% of design feedwater flow
- Other parameters have corresponding limits
- Steady state generation (constant load)
- Test code equations and methodology corrects design performance conditions to actual test conditions for comparison with actual measured values

# Feedwater Heater Zones
# One to three possible zones

- Desuperheating – applicable to fossil unit HP heaters, cools steam to within 5 – 50 deg of saturation temp
- Condensing – latent heat of condensation
- Drain Cooling – Subcools drains below saturation temperature for ease of transport to lower pressure heater and for efficiency
  - Can exist separately or as part of a two or three zone heater

# Heat Transfer Equations Utilized
# Resistances

- $U = 1/(r_{shell\ film} + r_{shell\ fouling} + r_{t\ fouling} + r_{metal} + r_{t\ film})$
  - Overall heat transfer coefficient
  - Utilized to obtain shell side film resistance
  - Supplied by heater manufacturer for each zone
- $r_{shell\ fouling} + r_{t\ fouling}$ are constants
- $R_{metal}$ = Tube wall conduction

  $= d_o/24K (\ln (d_o/d_i))$
- $R_{t\ film}$ = Tube side convection

  $=0.0378((u^{0.4}/(K^{0.6}p^{0.8}C_p{}^{0.4}))(do/di^{0.8})(1/V^{0.8})$

  $= 1/ (0.023 (Re^{0.8})(Pr^{\ 0.4}))$

# Heat Transfer Equations Applied to Each Zone

- $U = 1/(r_{shell\ film} + r_{shell\ fouling} + r_{t\ fouling} + r_{metal} + r_{t\ film})$
- Uses NTUs with the heat transfer resistances to calculate the performance
- Heat capacity flow rates
  - $C_{shell\ side} = W_{s\ actual} Q/(W_{s\ design}(T_1 - T_2)$
  - $c_{fw\ side} = w_{fw\ actual} Q/(w_{fw\ design}(t_2 - t_1)$
- Heat capacity ratio = R = $c_{fw\ side} / C_{shell\ side}$
- Number of transfer units = NTU = $UA/c_{fw\ side}$

# Heat Transfer Equations

- Zone effectiveness = for DS and DC Zones:

$E = (1 - e^{(NTU * (R-1)})/(1 - Re^{(NTU * (R-1)})$

$E = 1 - e^{-NTU}$ for condensing zone only

- Feedwater temperature leaving zone =

$T_{fw\ out} = E(T_{shell\ side\ in} – t_{fw\ in}) + t_{fw\ in}$

- Need to perform calculations for each zone in heater beginning with drain cooling zone and ending in desuperheat zone
- Iteratively converge to solution that satisfies an energy balance
- Calculate TTD and DCA

# Performance

- Terminal Temperature Difference

$TTD = T_{sat} – T_{fw\ outlet}$

- Drain Cooler Approach (if applicable)

$DCA = T_{drain\ out} – T_{fw\ inlet}$

# Design data corrections
# Pressure Drops

- Pressure Drops adjustments
  - $\Delta P_{shell} = \Delta P_{design} (W_{s\ actual}/W_{s\ design})^{1.8}$
    - Performed in each heater zone
    - Assumed negligible in condensing zone
  - $\Delta p_{fw} = \Delta p_{design} (w_{fw\ actual}/w_{fw\ design})^{1.8}$

# Design Data Corrections
# Heat Transfer Resistances

- Heat Transfer Resistances – Each Zone
- $r_{shell\ film}$, $r_{metal}$ , $r_{t\ film}$, $r_{shell\ fouling}$, $r_{t\ fouling}$
- $r_{shell\ film} = r_{shell\ film\ design}\ (W_{s\ design}/W_{s\ actual})^{0.6}$
- $r_{metal}$ - adjusted for temperature effect on K
- $r_{fw\ film} = r_{fw\ film\ design}\ (w_{fw\ design}/w_{fw\ actual})^{0.8}$
- $r_{shell\ fouling}$ and $r_{t\ fouling}$ are constants

# PEPSE Calculations

- Incorporates all the PTC code methodology and calculations
- User inputs data from manufacturers design spreadsheet plus resistance data that can be easily calculated
- PEPSE calculates the off design predictions and compares to actual performance

# Heater Specification Sheet Data

| | | Shell Side | | Tube Side |
|---|---|---|---|---|
| 5. Fluid Circulating | | Steam | Drains | Feedwater |
| 6. Total Fluid Entering | Lb/Hr | 51,365 | 91,612 | 1,134,590 |
| 7. | | | | |
| 8. Inlet Enthalpy | Btu/Lb | 1444.9 | 399.9 | 338.9 |
| 9. Outlet Enthalpy | Btu/Lb | | 351.5 | 392.3 |
| 10. Inlet Temperature | Deg. F | 843.7 (410.8 SAT.) | | 363.1 |
| 11. Outlet Temperature | Deg. F | | 378.1 | 413.8 |
| 12. Operating Pressure | Psia | 279.19 | | |
| 13. Number of Passes | | 3 Zones | | 2 Pass |
| 14. Velocity | Ft/Sec | | | 6.82 @ 388.5 Deg. F |
| 15. Pressure Drop | Psi | DSH 4.0 | DC 1.0 | 6.8 |

| | Heat Exchanged Btu / Hr | Surface Sq. Ft Effective | LMTD Deg. F | Transfer Rate Btu/ Hr*Sq. Ft* F | Baffle Spacing in | Reference Temperature Differences |
|---|---|---|---|---|---|---|
| 16. Desuperheating Zone | 10618000 | 558 | 186.3 | 102 | | |
| 17. Condensing Zone | 45146000 | 3628 | 16.9 | 737 | | TTD -3.0 Deg. F |
| 18. Drain Subcooling Zone | 4829000 | 395 | 26.3 | 464 | | DCA 15.0 Deg. F |

**CONSTRUCTION-EACH SHELL**

| | | Shell Side | Tube Side |
|---|---|---|---|
| 19. Design Pressure | Psig | 360.00 /FV | 3000 |
| 20. Test Pressure | Psig | 468 | 3900 |
| 21. Design Temperature (Max) | Deg. F | Shell 650.0 Skirt 920.0 | 450.0 |
| 22. Tubes Note #1 | (U's) 418 | O.D. 0.75 Avg. 0.073 | Length 335 in |

# Resistance data – PEPSE Inputs Available from manufacturer or can be calculated

- R $_{metal}$ = $d_o/24K (\ln (d_o/d_i))$
- R $_{Feedwater\ film}$ = $0.0378((u^{0.4}/(K^{0.6}p^{0.8}C_p{}^{0.4}))(do/di^{0.8})(1/V^{0.8})$
- U = $1/(r_{shell\ film} + r_{shell\ fouling} + r_{t\ fouling} + r_{metal} + r_{t\ film})$

utilized to obtain shell side film resistance

# PEPSE inputs for Design Data

**Three Zone Heater (Type 18)**

| Term | Units | Desuperheating Symbol | Desuperheating Value | Condensing Symbol | Condensing Value | Drain Cooling Symbol | Drain Cooling Value |
|---|---|---|---|---|---|---|---|
| **Design Data (supplied by manufacturer)** | | | | | | | |
| Feedwater flow rate | ( lbm/hr ) | | | $w'$ | 1134590 | | |
| Steam flow rate | ( lbm/hr ) | $W'_s$ | 51365 | | | | |
| Drains flow rate | ( lbm/hr ) | | | | | $W'_1$ | 142977 |
| Steam inlet pressure | ( psi ) | $P'_3$ | 279.19 | | | | |
| Shell side pressure loss | ( psi ) | $\Delta P'_{ds}$ | 4 | | | $\Delta P'_{dc}$ | 1 |
| Shell side temperature in | ( °F ) | $T'_3$ | 843.7 | $T'_2$ | 409.51 | | |
| Shell side temperature out | ( °F ) | $T'_{ds}$ | 464.3477 | | | $T'_1$ | 378.1 |
| Feedwater temperature in | ( °F ) | | | | | $t'_1$ | 363.1 |
| Feedwater temperature out | ( °F ) | $t'_4$ | 413.79 | $t'_3$ | 405.01 | $t'_2$ | 367.20 |
| Feedwater pressure loss | ( psi ) | | | $\Delta p'_t$ | 6.8 | | |
| Heat transferred | ( Btu/hr ) | $Q'_3$ | 10618000 | $Q'_2$ | 45146000 | $Q'_1$ | 4829000 |
| Heat transfer area | ( ft^2 ) | $A'_3$ | 558 | $A'_2$ | 3628 | $A'_1$ | 395 |
| Feedwater film resistance | ( hr-ft^2-°F/Btu ) | $r'_{t3}$ | 0.0004 | $r'_{t2}$ | 0.00041 | $r'_{t1}$ | 0.00042 |
| Feedwater fouling resistance | ( hr-ft^2-°F/Btu ) | $r'_{ft3}$ | 0.000237 | $r'_{ft2}$ | 0.000237 | $r'_{ft1}$ | 0.000237 |
| Tube material resistance | ( hr-ft^2-°F/Btu ) | $r'_{m3}$ | 0.000271 | $r'_{m2}$ | 0.000271 | $r'_{m1}$ | 0.000271 |
| Shell side fouling resistance | ( hr-ft^2-°F/Btu ) | $r'_{fs3}$ | 0.0003 | $r'_{fs2}$ | 0 | $r'_{fs1}$ | 0.0003 |
| Shell side film resistance ($r'_{s1}$ corrected for reheat by the manufacturer) | ( hr-ft^2-°F/Btu ) | $r'_{s3}$ | 0.008596 | $r'_{s2}$ | 0.00044 | $r'_{s1}$ | 0.000928 |
| Terminal temperature difference and Drain cooler approach | ( °F ) | $TTD'$ | -3 | | | $DCA'$ | 15 |

# PEPSE Inputs for Test Data

| Line No. | Term | Units | Desuperheating Symbol | Desuperheating Value | Condensing Symbol | Condensing Value | Drain Cooling Symbol | Drain Cooling Value |
|---|---|---|---|---|---|---|---|---|
| 18 | Terminal temperature difference and Drain cooler approach | ( °F ) | TTD' | -3 | | | DCA' | 15 |
| | **Test Data** | | | | | | | |
| 19 | Actual feedwater flow rate | ( lbm/hr ) | | | $w$ | 1134590 | | |
| 20 | Actual shell side temperature in | ( °F ) | $T_3$ | 843.7 | | | | |
| 21 | Actual shell side temperature out | ( °F ) | | | $T_2$ | | $T_1$ | 378.1 |
| 22 | Actual feedwater outlet temperature | ( °F ) | $t_4$ | 413.79 | | | | |
| 23 | Actual feedwater inlet temperature | ( °F ) | | | | | $t_1$ | 363.1 |
| 24 | Actual shell side pressure loss | ( psi ) | $\Delta P_{ds}$ | | | | $\Delta P_{dc}$ | |
| 25 | Actual feedwater pressure loss | ( psi ) | | | $\Delta p_t$ | 6.8 | | |
| 26 | Actual steam pressure in | ( psi ) | $P_3$ | 279.19 | $P_2$ | | | |
| 27 | Actual drain pressure out | ( psi ) | | | $P_1$ | 274.19 | | |
| 28 | Actual feedwater pressure in | ( psi ) | | | $p_1$ | 2350 | | |
| 29 | Actual feedwater pressure out | ( psi ) | $p_4$ | 2343.2 | | | | |
| 30 | Shell side fouling resistance (by agreement) | ( hr-ft^2-°F/Btu ) | $r_{fs3}$ | 0.0003 | $r_{fs2}$ | 0 | $r_{fs1}$ | 0.0003 |
| 31 | Feedwater fouling resistance (by agreement) | ( hr-ft^2-°F/Btu ) | $r_{ft3}$ | 0.000237 | $r_{ft2}$ | 0.000237 | $r_{ft1}$ | 0.000237 |
| 32 | ☐ Feedwater fouling resistance is ID based | | | | | | | |
| 33 | Actual drain outlet flow rate | ( lbm/hr ) | | | | | $W_1$ | 142977 |
| 34 | Number of drain inlet connections [1 ▾] | | | | | | | |
| 35 | Actual 1st drains inlet pressure | ( psi ) | | | $P_{d1}$ | 275.2 | | |
| 36 | Actual 1st drains inlet temperature | ( °F ) | | | $T_{d1}$ | 409.51 | | |
| 37 | Actual 1st drains inlet flow rate | ( lbm/hr ) | | | $W_{d1}$ | 91612 | | |

# PEPSE Outputs

PTC12.1-UGM.xls [Compatibility Mode] - Microsoft Excel

I10 | 385.422485351562

**Computed Data**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 38 | Steam flow rate | ( lbm/hr ) | | | $W^*_s$ | 52755.38 | | |
| 39 | Feedwater enthalpy in | ( Btu/lbm ) | | | $h_1$ | 338.8809 | | |
| 40 | Feedwater enthalpy out | ( Btu/lbm ) | $h^*_4$ | 392.4411 | | | | |
| 41 | Steam enthalpy in | ( Btu/lbm ) | $H_3$ | 1444.913 | | | | |
| 42 | Drains enthalpy in | ( Btu/lbm ) | | | $H_d$ | 385.4225 | | |
| 43 | Drain enthalpy out | ( Btu/lbm ) | | | | | $H^*_1$ | 351.7 |
| 44 | Assumed feedwater outlet temperature | ( °F ) | $t^*_{4a}$ | 413.9243 | | | | |
| 45 | Total heat load | ( Btu/hr ) | | | $Q^*$ | 60768788 | | |
| 46 | Feedwater pressure loss | ( psi ) | | | $\Delta p^*_t$ | 6.8 | | |
| 47 | Steam pressure in condensing zone | ( psi ) | | | $P^*_2$ | 274.993 | | |
| 48 | Saturated steam temperature at steam inlet $P_3$ | ( °F ) | $T_s$ | 410.8093 | | | | |
| 49 | Drains flow rate | ( lbm/hr ) | | | $W_{dt}$ | 91612 | $W^*_1$ | 144367 |
| 50 | Shell side temperature in | ( °F ) | | | $T^*_2$ | 409.4452 | $T^*_2$ | 409.4452 |
| 51 | Shell side temperature out | ( °F ) | | | $T^*_2$ | 409.4452 | $T^*_1$ | 378.2129 |
| 52 | Feedwater film resistance | ( hr-ft^2-°F/Btu ) | $r^*_{t3}$ | 0.0004 | $r^*_{t2}$ | 0.00041 | $r^*_{t1}$ | 0.00042 |
| 53 | Shell side film resistance | ( hr-ft^2-°F/Btu ) | $r^*_{s3}$ | 0.00846 | | | $r^*_{s1}$ | 0.000923 |
| 54 | Overall heat transfer coefficient | ( Btu/hr-ft^2-°F ) | $U^*_3$ | 103.4419 | $U^*_2$ | 737 | $U^*_1$ | 465.1596 |
| 55 | Hourly heat capacity flow rate of shell side fluid | ( Btu/(hr-°F) ) | $C^*_3$ | 28747.46 | | | $C^*_1$ | 155235.9 |
| 56 | Hourly heat capacity flow rate of feedwater fluid | ( Btu/(hr-°F) ) | $c^*_3$ | 1209220 | $c^*_2$ | 1194160 | $c^*_1$ | 1176799 |
| 57 | Hourly heat capacity ratio | ( -- ) | $R^*_3$ | 42.06355 | | | $R^*_1$ | 7.580715 |
| 58 | Number of transfer units | ( -- ) | $(NTU)^*_3$ | 0.047734 | $(NTU)^*_2$ | 2.239093 | $(NTU)^*_1$ | 0.156134 |
| 59 | Effectiveness | ( -- ) | $\varepsilon^*_3$ | 0.020494 | $\varepsilon^*_2$ | 0.893445 | $\varepsilon^*_1$ | 0.088897 |
| 60 | Feedwater outlet temperature | ( °F ) | $t^*_4$ | 413.9376 | $t^*_3$ | 404.9459 | $t^*_2$ | 367.22 |
| 61 | Predicted terminal temperature difference | ( °F ) | $TTD^*$ | -3.12837 | | | | |
| 62 | Predicted drain cooler approach | ( °F ) | | | | | $DCA^*$ | 15.11285 |
| 63 | Predicted shell side pressure loss | ( psi ) | $\Delta P^*_{ds}$ | 4.197001 | | | $\Delta P^*_{dc}$ | 1.017572 |
| 64 | Actual test point shell side pressure loss | ( psi ) | $\Delta P_{ds^*}$ | 279.19 | | | $\Delta P_{dc^*}$ | -274.19 |
| 65 | Actual test point terminal temperature difference | ( °F ) | $TTD$ | -2.98076 | | | | |
| 66 | Actual test point drain cooler approach | ( °F ) | | | | | $DCA$ | 15 |
| 67 | Discrepancy of shell side pressure loss | ( psi ) | $\delta P_{ds}$ | -274.993 | | | $\delta P_{dc}$ | 275.2076 |
| 68 | Actual feedwater pressure loss | ( psi ) | | | $\Delta P_t$ | 6.8 | | |
| 69 | Discrepancy of feedwater side pressure loss (FWH) | ( psi ) | | | $\delta P_r$ | 0 | | |
| 70 | Assumed drain cooling zone drain outlet temp | ( °F ) | | | | | $T^*_{1a}$ | 378.1 |
| 71 | Discrepancy of drain cooler approach | ( °F ) | | | | | $\delta DCA$ | 0.112854 |
| 72 | Discrepancy of terminal temperature difference | ( °F ) | $\delta TTD$ | -0.14761 | | | | |

Select | Input | **Output** | Prelim Inputs

Ready

# Comparisons to Design
# Actual to Corrected Design

- Calculated zone heat transfer coefficients
- **TTD**
- **DCA** (if applicable)
- Zone shell pressure drops
- Feedwater pressure drop

# Future Enhancement Ideas From Beta Test on 3 Zone Heater

- Incorporate resistance calculations
- Revise the input sheet to designate as optional parameters that can be calculated:
  - Shell side temp leaving condensing zone
  - DS zone pressure drop
  - DC zone pressure drop
  - Condensing zone pressure
  - Note that these are zone dependent and data will be needed for single zone heater

# Reference

- ASME PTC 12.1 – 2000 version