A.H. LUNDBERG SYSTEMS LIMITED
SOLUTIONS FOR THE PULP & PAPER INDUSTRY

- Engineering
- Energy
- Environmental
- Evaporation
- Equipment
HEAT EXCHANGER EVALUATION

CASE STUDIES & A BIT OF THEORY

BY BRUCE DER

PRESENTED TO PAPTAC STEAM, STEAM POWER, & ENERGY COMMITTEE JOINT MEETING DECEMBER 6, 2006
YOUR HEAT EXCHANGER SITUATION

- EXISTING UNIT NEEDS EVALUATION
- EXISTING UNIT NEEDS UPGRADE OR RECONFIGURATION
- USED UNIT IN NEW APPLICATION
- NEW UNIT IN NEW APPLICATION

EXISTING HEAT EXCHANGER OPTIONS

- RECONFIGURATION – CHANGE PROCESS, CHANGE SIDES
- RETROFIT – MODIFY UNIT: NUMBER OF PASSES, NEW TUBE BUNDLE, ADD PLATES
- AUGMENTATION – ADD SURFACE AREA
- REPLACEMENT – NEW UNIT
HEAT EXCHANGER EVALUATION - THEORY
FOURIER GENERAL EQUATION

\[ Q = U A \Delta t \]

\[ Q = \text{HEAT FLOW, BTU/h} \]
\[ U = \text{OVERALL HEAT TRANSFER COEFFICIENT, BTU/hft}^2\text{°F} \]
\[ A = \text{HEAT TRANSFER SURFACE, ft}^2 \]
\[ \Delta t = \text{LMTD OR LOGARITHMIC MEAN TEMPERATURE DIFFERENCE, °F} \]
Q = HEAT FLOW

\[ Q = m \times c_p \times (T_1 - T_2) \]

- \( m \) = mass flow, lb/h
- \( c_p \) = specific heat, BTU/lb°F
- \( T_1 \) = inlet hot side fluid temperature
- \( T_2 \) = outlet hot side fluid temperature
U = OVERALL HEAT TRANSFER COEFFICIENT

- CAN BE $U_o$ (OUTSIDE) OR $U_i$ (INSIDE)
- $U_o = \text{inverse sum of resistances} = \frac{1}{1/h_o + 1/h_{io} + R_w + R_d}$
  - $h_o = \text{outside film coefficient}$
  - $h_{io} = \text{inside film coefficient}$
  - $R_w = \text{resistance of wall}$
  - $R_d = \text{fouling resistance}$
A = HEAT TRANSFER SURFACE

- CAN BE $A_o$ (OUTSIDE) OR $A_i$ (INSIDE)
- EVAPORATORS USUALLY $A_i$, SC $A_o$
- OTHER SERVICES USUALLY $A_o$
- DIFFERENCE ON 1" x 18 ga (0.049") TUBE IS $1 - (1 - 2 \times 0.049)/1 = 9.8\%$
Δt = LMTD: COUNTERCURRENT

\[ (T_1 - t_2) - (T_2 - t_1) \]

\[ Δt = \frac{\ln (T_1 - t_2)}{(T_2 - t_1)} \]

WBL COOLER COUNTER-CURRENT
HOT SIDE (LIQUOR) 212 → 185
COLD SIDE (WATER) 160 ← 110
DIFFERENCE 52 - 75 = -23
LMTD = -23 / LN (52/75) = 62.8°F

\[ \Delta t = \text{LMTD: CO-CURRENT} \]
\[ (T_1 - t_1) - (T_2 - t_2) \]
\[ \Delta t = \frac{\ln (T_1 - t_1)}{(T_2 - t_2)} \]

**EXAMPLE: WBL COOLER CO-CURRENT**

**HOT SIDE (LIQUOR)**  \[ 212 \rightarrow 185 \]

**COLD SIDE (WATER)**  \[ 110 \rightarrow 160 \]

**DIFFERENCE**  \[ 102 - 25 = 77 \]

**LMTD**  \[ 77 / \ln (102/25) = 54.8^\circ F \]

\( h_0 = \text{OUTSIDE LIQUID FILM COEFFICIENT} \)

\[
a_s = \text{ID} \times C' \times B / 144 / P_T \\
G_S = W / a_s \\
\text{Re}_S = D_e \times G_s / \mu \\
\text{Using Re}_S, \text{ get } j_H \text{ from Kern, Figure 28} \\
h_o = j_H \times k / D_e \times (c_\mu/k)^{(1/3)} \times (\mu/\mu_w)^{0.14}
\]
$h_{io} = \text{INSIDE LIQUID FILM COEFFICIENT}$

\[
a_t = \text{no. tubes} \times \text{flow area/tube} / \text{passes} \\
G_t = w / a_t \\
Re_t = D \times G_t / \mu \\
\text{Using } Re_t, \text{ get } j_H \text{ from Kern, Figure 24} \\
h_i = j_H \times k / D \times (c*\mu/k)^{1/3} \times (\mu/\mu w)^{0.14} \\
h_{io} = h_i \times \text{tube ID} / \text{tube OD}
\]
TYPICAL FILM COEFFICIENTS

- **STEAM ~ 1500 BTU/hft$^{2^\circ}$F, LIMITED BY HEAT FLUX**
- **WATER ~ 200 TO 1000 BTU/hft$^{2^\circ}$F, DEPENDENT ON VELOCITY**
- **AIR ~ 10 BTU/hft$^{2^\circ}$F, DEPENDENT ON TURBULENCE/VELOCITY**
## WALL RESISTANCE

<table>
<thead>
<tr>
<th>Material</th>
<th>T/K = THICKNESS / CONDUCTIVITY</th>
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</thead>
<tbody>
<tr>
<td>304 SS X 18 GAUGE</td>
<td>0.049 / 108 = 0.00045</td>
</tr>
<tr>
<td>316 SS X 18 GAUGE</td>
<td>0.049 / 98.4 = 0.0005</td>
</tr>
<tr>
<td>TITANIUM X 20 GAUGE</td>
<td>0.035 / 147.6 = 0.00024</td>
</tr>
</tbody>
</table>
CALCULATING OVERALL $U_o$

EXAMPLE: KAMYR SEC BLACK LIQUOR COOLER
TUBE SIDE = WEAK LIQUOR
SHELL SIDE = WATER

$U_o =$ inverse sum of resistances

$$= 1/(1/h_o + 1/h_{io} + R_w + R_d)$$

$$= (1/748 + 1/1071 + 0.00045 + 0.003)^{-1}$$

$$= 1 / 0.00572 = 175$$
TUBE SIDE PRESSURE DROP EQUATIONS

\[ \Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.21 \times 10^{10} \times D \times \sqrt{(\mu/\mu_w)^{0.14}}} \text{ PSI} \]

\[ \Delta P_r = \frac{4 \times n \times V^2 \times 62.43}{s \times 2 \times g' \times 144} \text{ PSI} \]
SHELL SIDE PRESSURE DROP EQUATION

\[ \Delta P_S = f \times G_s^2 \times D_s \times (N+1) \]

\[ 5.21 \times 10^{10} \times D_e \times s \times (\mu/\mu_w)^{0.14} \]
RULES OF THUMB

- CONDENSERS IN SERIES OR PARALLEL → SAME
- MULTIPLE PASS LIQ TO LIQ → MUST BE IN SERIES
- MTD CORRECTION FACTOR > 0.80
- TRIANGULAR PITCH → COMMON, LOW IN COST, CANNOT CLEAN TUBES
- SQUARE TUBE PITCH → BIGGER DIAMETER, MORE $, CAN CLEAN TUBES
- COMMON TUBES → 1” X 18 GA, 1.25” X 16 GA
- LONGER TUBES → GENERALLY LOWER IN COST
- SMALLER TUBES → SMALLER DIAMETER, LOWER IN COST
- MORE SHELLS → MORE COST
RULES OF THUMB

• MORE BAFFLES $\Rightarrow$ BETTER HEAT TRANSFER, BETTER TUBE SUPPORT, BUT MORE $dP$

• IF $V < 3$ FPS, DIRT & SLIME FROM MICRO-ORGANIC ACTION ADHERES TO TUBE WALLS THAT WOULD OTHERWISE BE CARRIED AWAY WITH HIGHER VELOCITIES
HEAT EXCHANGER EVALUATION – CASE STUDIES
1. SURFACE CONDENSER ADDITION

ISSUES

- HEAT TREATED WATER TO DEAERATORS
- EXISTING CONCENTRATOR SURF COND → ADD BEFORE OR AFTER, IN SERIES OR IN PARALLEL?
SC ADDITION - FLOWSHEET

140,000 LB/H  212°F VAPOUR
NEW TREATED WATER HEATER

107,000 LB/H  212°F VAPOUR
EXISTING SURFACE CONDENSER

640,000 LB/H  190°F TW
640,000 LB/H  140°F TW
SC ADDITION
– KEY DESIGN ISSUES

- HEAT TREATED WATER TO GOOD TEMP, 140 → 190°F
- TOO MUCH VAPOUR → BYPASSED 40% VIA BUSTLE, BALANCED PRESSURE DROPS TO BUNDLE & AROUND BUSTLE
- VAPOUR LINE PRESSURE DROP → OVERSIZED LINE
- TUBE VIBRATION → ANALYSIS, SUPPORT BAFFLES
SC ADDITION - RESULTS

- $Q = 32\text{ MM BTU/H}$
- 6 TUBE PASSES
- $A_0 = 4008\text{ FT}^2$, 1 SHELL
- $PD = 5.8\text{ PSI}$
2. GREEN LIQUOR COOLER REPLACEMENT

ISSUES

- EXISTING UNIT UNDERSIZED → COOLING WATER TEMP TOO LOW, POOR HEAT RECOVERY
- TUBE PLUGGING
GLC REPLACEMENT - FLOWSHEET

EXISTING
GREEN LIQUOR COOLER

NEW
GREEN LIQUOR COOLER

400 GPM 205°F
GREEN LIQUOR

288 GPM 100°F
WATER

650 GPM 205°F
GREEN LIQUOR

137 GPM 158°F
WATER

400 GPM 190°F
GREEN LIQUOR

288 GPM 80°F
WATER

650 GPM 188°F
GREEN LIQUOR

137 GPM 80°F
WATER
GLC REPLACEMENT - KEY DESIGN ISSUES

- PLUGGING → USE LARGER TUBES 5/8 → 1"
- CLEANING → REASONABLE LENGTH OF TUBE 14 FT
- HIGH QUALITY PROC WATER → EXISTING 100°F, NEW 158°F
- DIFFERENTIAL EXPANSION → EXPANSION JOINT ADDED
## GLC REPLACEMENT - RESULTS

<table>
<thead>
<tr>
<th></th>
<th>NEW</th>
<th>EXISTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q MMBTU/H</td>
<td>5.3</td>
<td>2.8</td>
</tr>
<tr>
<td>AREA FT(^2)</td>
<td>553</td>
<td>144</td>
</tr>
<tr>
<td>TUBES</td>
<td>1” x 18 BWG</td>
<td>5/8” x 18 BWG</td>
</tr>
</tbody>
</table>
3. STRIPPER PREHEATER RECONFIGURATION

ISSUES

- TUBE SIDE FOULING AFTER 2 TO 3 WEEKS OPERATION → LOSS OF HEAT TRANSFER. WHEN CLEAN 38 MM Btu/h, LESS THAN 1/2 WHEN FOULED
- LOSS OF TRS STRIPPING EFFICIENCY → ODOUR
- FREQUENT CLEANING → DOWNTIME, ENVIRONMENTAL ISSUE, NUISANCE

STRIPPER PREHEATER RECONF’N – KEY DESIGN ISSUES

- REDUCE FOULING $\rightarrow$ MINIMUM VELOCITY 3 FPS REQUIRED, CONVERT ALL 4 SHELLS FROM 2 PASSES TO 4 PASSES
- ADDING 2 CHANNEL PARTITION PLATES $\rightarrow$ LOSS OF SURFACE AREA (42 TUBES)
- UNEVEN TUBES PER PASS $\rightarrow$ 10% DIFFERENCE
- HIGHER PRESSURE DROP $\rightarrow$ EXISTING PUMP OK
- WORK COMPLETED DURING SHUTDOWN

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<thead>
<tr>
<th></th>
<th>BEFORE</th>
<th>AFTER</th>
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<tbody>
<tr>
<td>TUBE PASSES</td>
<td>2 x 230 TUBES</td>
<td>4 x 104.5 TUBES</td>
</tr>
<tr>
<td>TUBE VELOCITY FPS</td>
<td>1.9</td>
<td>4.2</td>
</tr>
<tr>
<td>LOSS OF HEAT TRANSFER</td>
<td>WITHIN 2 WEEKS</td>
<td>SHUTDOWN: TUBES ARE CLEAN</td>
</tr>
<tr>
<td>TUBE SIDE DELTA P PSI</td>
<td>4.0</td>
<td>18.8</td>
</tr>
<tr>
<td>CLEANING</td>
<td>MONTHLY</td>
<td>BI-ANNUALLY</td>
</tr>
</tbody>
</table>

STRIPPER PREHEATER RECONF’N

- 2 ROWS OF TUBES PLUGGED OFF

STRIPPER PREHEATER RECONF’N

- TWO PARTITION PLATES ADDED

4. LIQUOR COOLER AUGMENTATION

ISSUES

- UNDERSIZED LIQUOR COOLER → INSUFFICIENT HEAT RECOVERY → TALK OF DOUBLING UP IN PARALLEL
- TOO MUCH MILL WATER CONSUMPTION
- LOW OUTLET WATER TEMP FOR WASHERS
- BATCH PROCESS → THERMAL EXPANSION → PREMATURE WELD FAILURE → HAD TO ADD 2ND EJ
- FLOATING HEAD LEAKS → EXPANSION JOINT
LIQUOR COOLER AUGMENTATION – KEY DESIGN ISSUES

- UNSIZED COOLER → ADDED A SECOND LARGER UNIT IN SERIES. NOT SAME SIZE, NOT IN PARALLEL
- REDUCE WATER USAGE → BOOST OUTLET TEMP TO 168°F
- BATCH CYCLICAL PROCESS → EJ FAILURE → DESIGN FOR 500,000 CYCLES
LIQUOR COOLER AUGMENTATION - RESULTS

<table>
<thead>
<tr>
<th></th>
<th>AFTER – 2 UNITS</th>
<th>BEFORE – 1 UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA FT²</td>
<td>2930 +4172 =7101</td>
<td>2930</td>
</tr>
<tr>
<td>Q MMBTU/H</td>
<td>96.9</td>
<td>65.8</td>
</tr>
<tr>
<td>MTD CORR FACTOR</td>
<td>0.973 / 0.950</td>
<td>0.972</td>
</tr>
<tr>
<td>WATER</td>
<td>2640 GPM, 125 → 200°F</td>
<td>1780 GPM, 41 → 111°F</td>
</tr>
<tr>
<td>LIQUOR</td>
<td>2700 GPM, 280 → 205°F</td>
<td>2700 GPM, 252 → 200°F</td>
</tr>
</tbody>
</table>

5. DIGESTER LIQUOR HEATER REPLACEMENT

ISSUES

- RAPID ORGANIC/INORGANIC SCALING → WASHING & DRILLING → LOSS OF TUBE METAL THICKNESS
- THERMAL EXPANSION → EXPANSION JOINT
- NO PIPING CHANGES TO SAVE $
- LIQUOR CIRCULATION PUMP AT MAXIMUM
- LIMITED SPACE
- EXISTING SURFACE AREA OK
LIQUOR HEATER REPLACEMENT – KEY DESIGN ISSUES

- REDUCE FOULING → MINIMUM VELOCITY 8 FPS REQUIRED
- THERMAL EXPANSION → DESIGN JOINT FOR 70,000 CYCLES
- NO PIPING CHANGES → LESS TUBES, LONGER TUBES → DESIGNED WITH STEAM BUSTLE
- HIGHER PRESSURE DROP → EXISTING PUMP MARGINAL

# DIGESTER LIQUOR HEATER REPLACEMENT - RESULTS

<table>
<thead>
<tr>
<th></th>
<th>NOW</th>
<th>ENGINEERING PHASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA FT²</td>
<td>1,664</td>
<td>1,675</td>
</tr>
<tr>
<td>TUBES</td>
<td>360 – 1.25”x16 BWG x 15′-9”</td>
<td>238 – 1.25”x16 BWG x 24’</td>
</tr>
<tr>
<td>TUBE VELOCITY FPS</td>
<td>5.4</td>
<td>8.2</td>
</tr>
<tr>
<td>TUBE SIDE DELTA P PSI</td>
<td>3.1</td>
<td>8.5</td>
</tr>
</tbody>
</table>

DIGESTER LIQUOR HEATER REPLACEMENT
6. BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER

ISSUES

- REUSE EXISTING SECOND HAND UNITS → 2 SHELLS, EACH 6016 ft² PROVIDED BY (766) 0.75” X 15 GA X 40 FT, 1 TUBE PASS PER SHELL
- NOT ENOUGH TUBE PASSES → ACCELERATED FOULING
2 SECOND HAND HEAT EXCHANGERS

2300 GPM 170°F
B C EFFLUENT

X GPM 160°F
WATER

2300 GPM T°F
B C EFFLUENT

X GPM 70°F
WATER
BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - HEAT DUTY Q

\[ m = 2300 \text{ gpm} \times 500.7 \text{ lb/h/gpm} \times 0.981 \]
\[ = 1,130,000 \text{ lb/h} \]

BY ITERATION, ASSUME \( t_2 = 124.3^\circ\text{F} \)

\[ Q_{\text{EFFL}} = 1,130,000 \times 1 \times (170 - 124.3) \]
\[ = 51.6 \text{ MMBTU/h} \]
BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - CHECK AREA

HOT SIDE (EFFLUENT) 170 → 124.3
COLD SIDE (WATER) 160 ← 70
DIFFERENCE 10 - 54.3 = -44.3
LMTD = -44.3 / LN (10/54.3) = 26.2°F

A = Q / (U₀ Δt)
   = 12,030 ft², SO CHECKS!

BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - PRESSURE DROPS & VELOCITIES

- $\Delta P_T = 4.0$ PSI
- $\Delta P_S = 9.8$ PSI
- TUBE VELOCITY $V = 3.3$ FPS
## BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - RESULTS

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>AREA FT²</strong></td>
<td>2 SHELLS x 6016</td>
</tr>
<tr>
<td><strong>Q MMBTU/H</strong></td>
<td>51.6</td>
</tr>
<tr>
<td><strong>WATER</strong></td>
<td>1160 GPM, 70 → 160°F</td>
</tr>
<tr>
<td><strong>LIQUOR</strong></td>
<td>2300 GPM, 170 → 124°F</td>
</tr>
</tbody>
</table>
CONCLUDING REMARKS

- WRONG: IF THE HX RUNS, LEAVE IT ALONE. RIGHT: MONITOR & OPTIMIZE FOR MAXIMUM ENERGY RECOVERY
- ADDING A HEAT EXCHANGER REQUIRES KNOWLEDGE OF BOTH THE PULP MILL PROCESS AND HEAT TRANSFER → HALF OF ALL HEAT EXCHANGERS ARE SPECIFIED INCORRECTLY!
- BEST TO HAVE AN ON-SITE PROCESS ENGINEER & AN OFF-SITE CONSULTANT TO ASSIST