A.H. LUNDBERG SYSTEMS LIMITED

SOLUTIONS FOR THE PULP & PAPER INDUSTRY

- ENGINEERING
- ENERGY
- ENVIRONMENTAL
- EVAPORATION
- EQUIPMENT

HEAT EXCHANGER EVALUATION

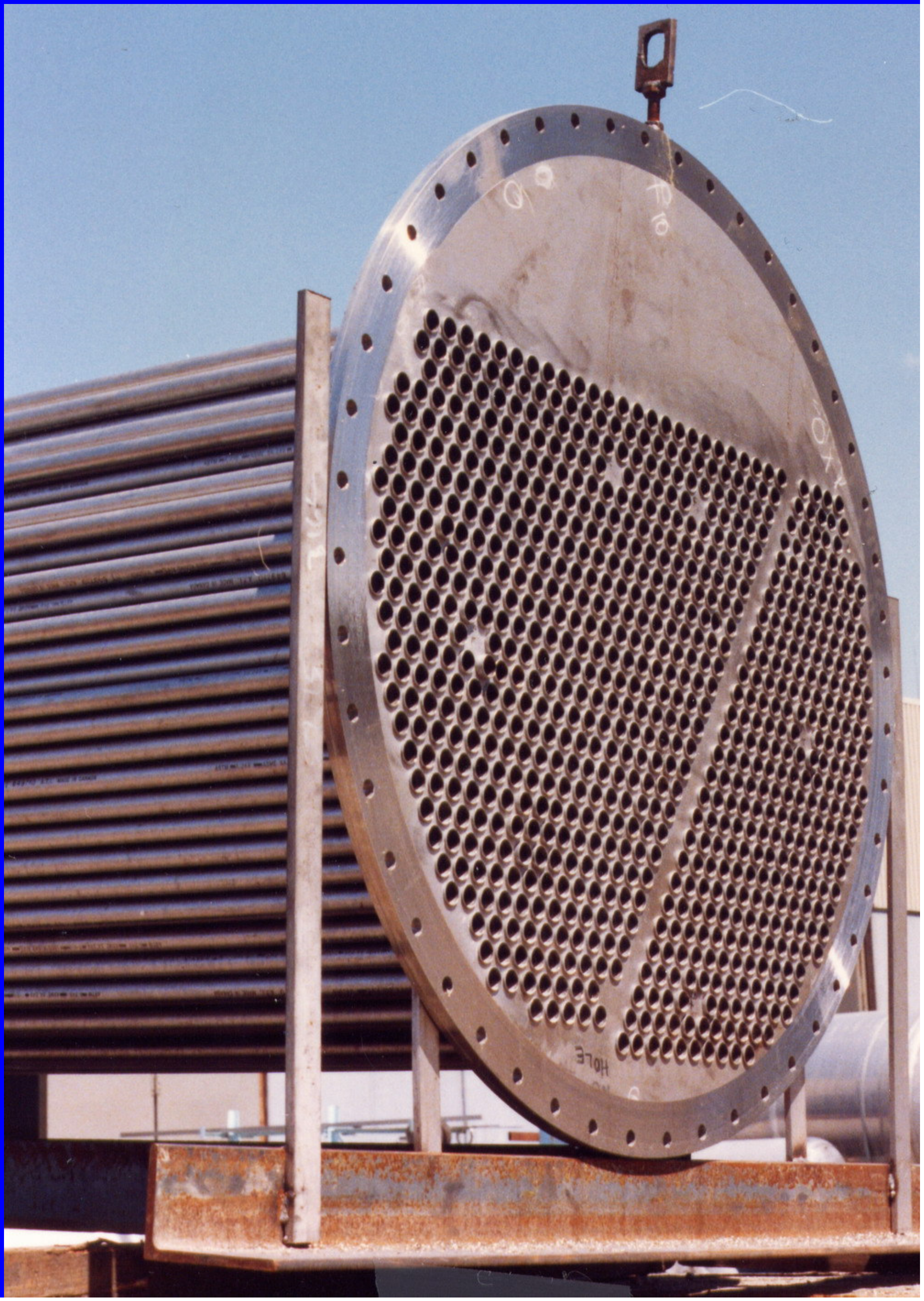
CASE STUDIES & A BIT OF THEORY

BY BRUCE DER

PRESENTED TO PAPTAC STEAM, STEAM POWER, & ENERGY COMMITTTEE JOINT MEETING DECEMBER 6, 2006

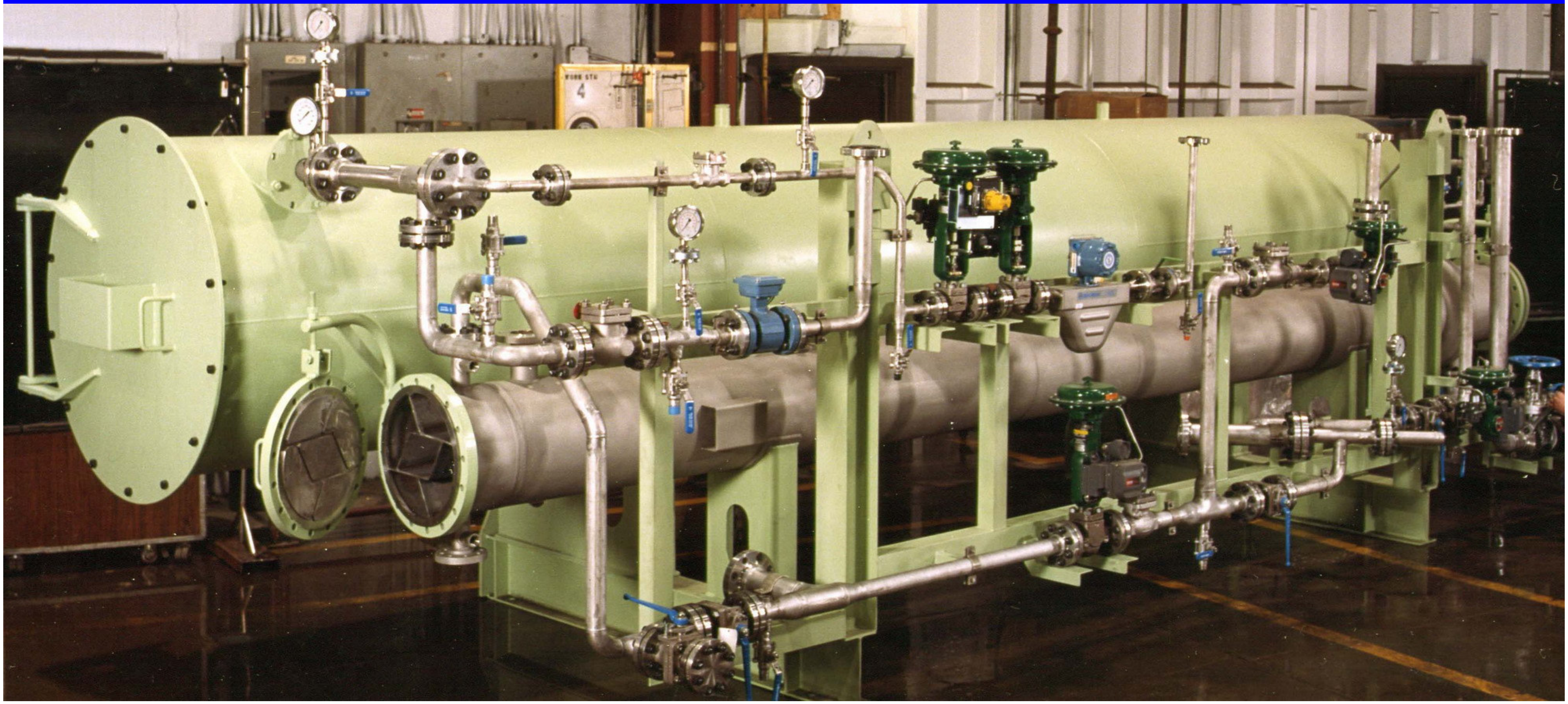
YOUR HEAT EXCHANGER SITUATION

- 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 = HEAT FLOW, BTU/h

U = OVERALL HEAT TRANSFER COEFFICIENT, BTU/hft^2°F

A = HEAT TRANSFER SURFACE, ft^2

Δt = LMTD OR LOGARITHMIC MEAN TEMPERATURE DIFFERENCE, °F

Q = HEAT FLOW

$Q = m * c_p * (T_1 - T_2)$

- 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 = inverse sum of resistances

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

  h_o = outside film coefficient

  h_{io} = inside film coefficient

  R_w = resistance of wall

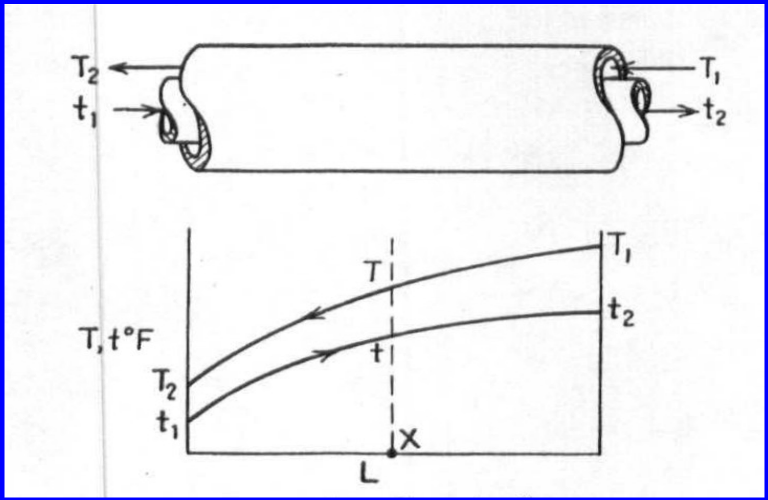
  R_d = fouling resistance

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*0.049)/1 = 9.8%

Δt = LMTD: COUNTERCURRENT

$$\Delta t = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln (T_1 - t_2) / (T_2 - t_1)}$$



WBL COOLER COUNTER-CURRENT

HOT SIDE (LIQUOR) 212 → 185

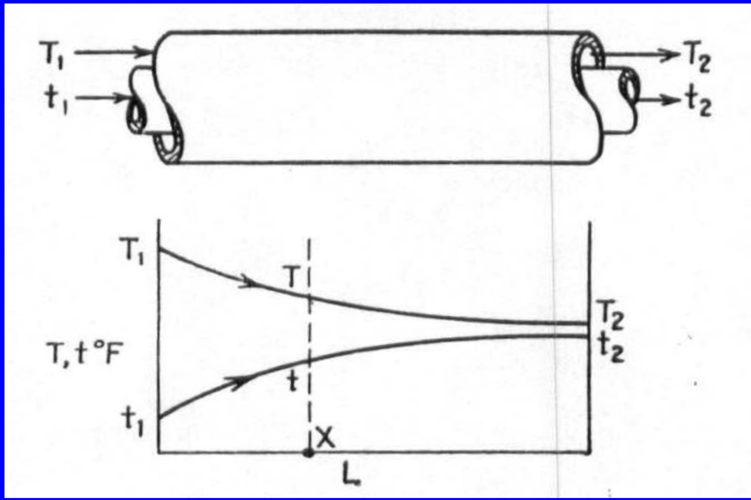
COLD SIDE (WATER) 160 ← 110

DIFFERENCE 52 - 75 = -23

LMTD = -23 / LN (52/75) = 62.8°F

Δt = LMTD: CO-CURRENT

$$\Delta t = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln (T_1 - t_1) / (T_2 - t_2)}$$



EXAMPLE: WBL COOLER CO-CURRENT

HOT SIDE (LIQUOR)	212 → 185
COLD SIDE (WATER)	110 → 160
DIFFERENCE	102 - 25 = 77

LMTD = 77 / LN (102/25) = 54.8°F

h_o= OUTSIDE LIQUID FILM COEFFICIENT

a_s = ID * C' * B / 144 / P_T

G_S = W / a_s

Re_S = D_e * G_s / μ

Using Re_S, get j_H from Kern, Figure 28

$h_o = j_H * k / D_e * (c*\mu/k)^{(1/3)} * (\mu/\mu w)^{0.14}$

h_{io}= INSIDE LIQUID FILM COEFFICIENT

a_t = no.tubes * flow area/tube / passes

$G_t = w / a_t$

$Re_t = D * G_t / \mu$

Using Re_t, get j_H from Kern, Figure 24

$h_i = j_H * k / D * (c*\mu/k)^{(1/3)} * (\mu/\mu w)^{0.14}$

$h_{io} = h_i$ * tube ID / tube OD

TYPICAL FILM COEFFICIENTS

- STEAM ~ 1500 BTU/hft^2°F, LIMITED BY HEAT FLUX
- WATER ~ 200 TO 1000 BTU/hft^2°F, DEPENDENT ON VELOCITY
- AIR ~ 10 BTU/hft^2°F, DEPENDENT ON TURBULENCE/VELOCITY

WALL RESISTANCE

	T/K = THICKNESS / CONDUCTIVITY
304 SS X 18 GAUGE	0.049 / 108 = 0.00045
316 SS X 18 GAUGE	0.049 / 98.4 = 0.0005
TITANIUM X 20 GAUGE	0.035 /147.6= 0.00024

CALCULATING OVERALL U_O

EXAMPLE: KAMYR SEC BLACK LIQUOR COOLER

TUBE SIDE = WEAK LIQUOR

SHELL SIDE = WATER

U_o = inverse sum of resistances

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

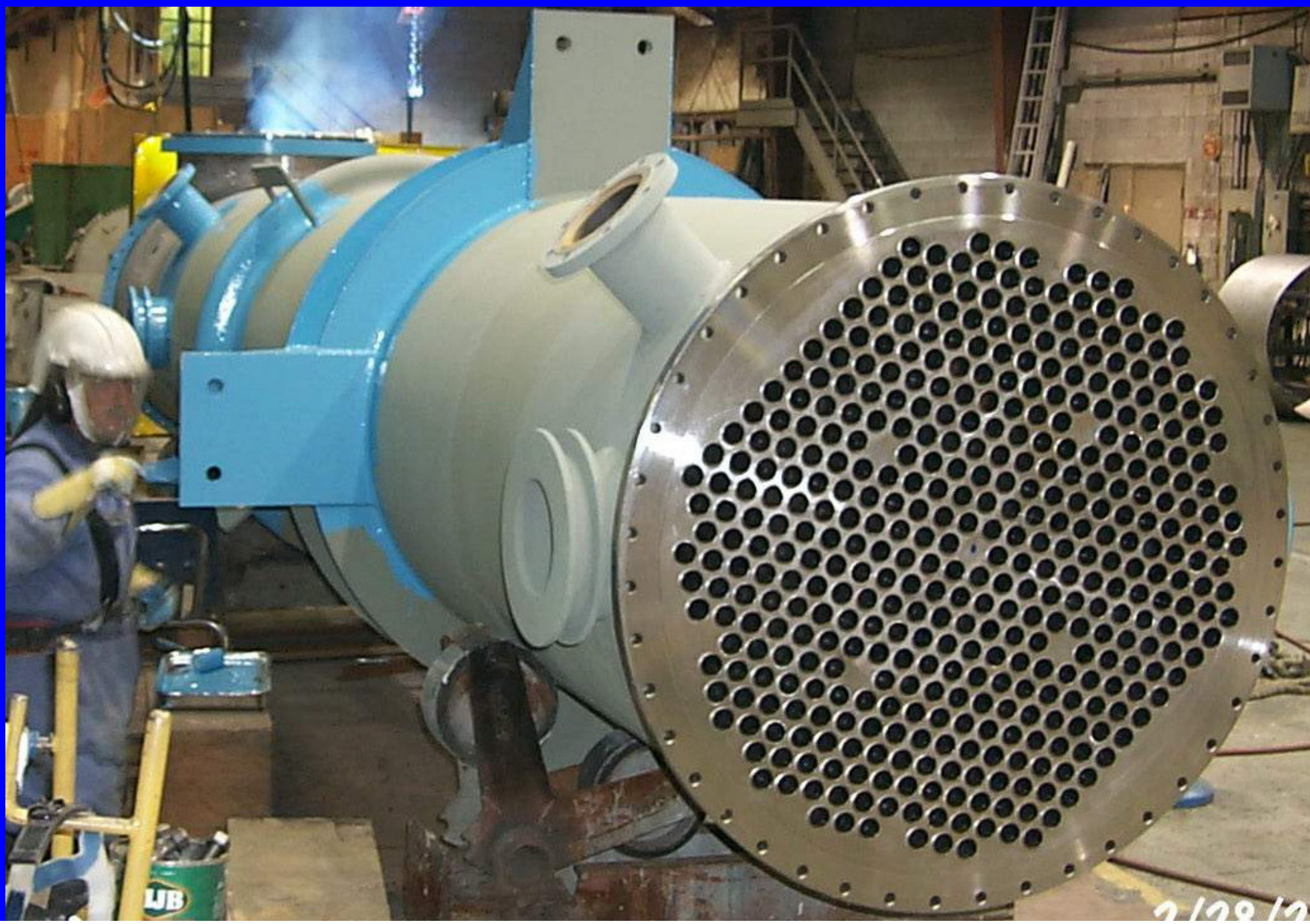
$= (1/748 + 1/1071 + 0.00045 + 0.003)^{-1}$

$= 1 / 0.00572 = 175$

TUBE SIDE PRESSURE DROP EQUATIONS

$$\Delta P_t = \frac{f * G_t^2 * L * n}{5.21 \times 10^{10} * D * s * (\mu/\mu w)^{0.14}} \text{ PSI}$$

$$\Delta P_r = \frac{4 * n * V^2 * 62.43}{s * 2 * g' * 144} \text{ PSI}$$



SHELL SIDE PRESSURE DROP EQUATION

$$\Delta P_S = \frac{f * G_S^2 * D_S * (N+1)}{5.21 \times 10^{10} * D_e * s * (\mu/\mu w)^{0.14}} \text{ PSI}$$

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 → 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

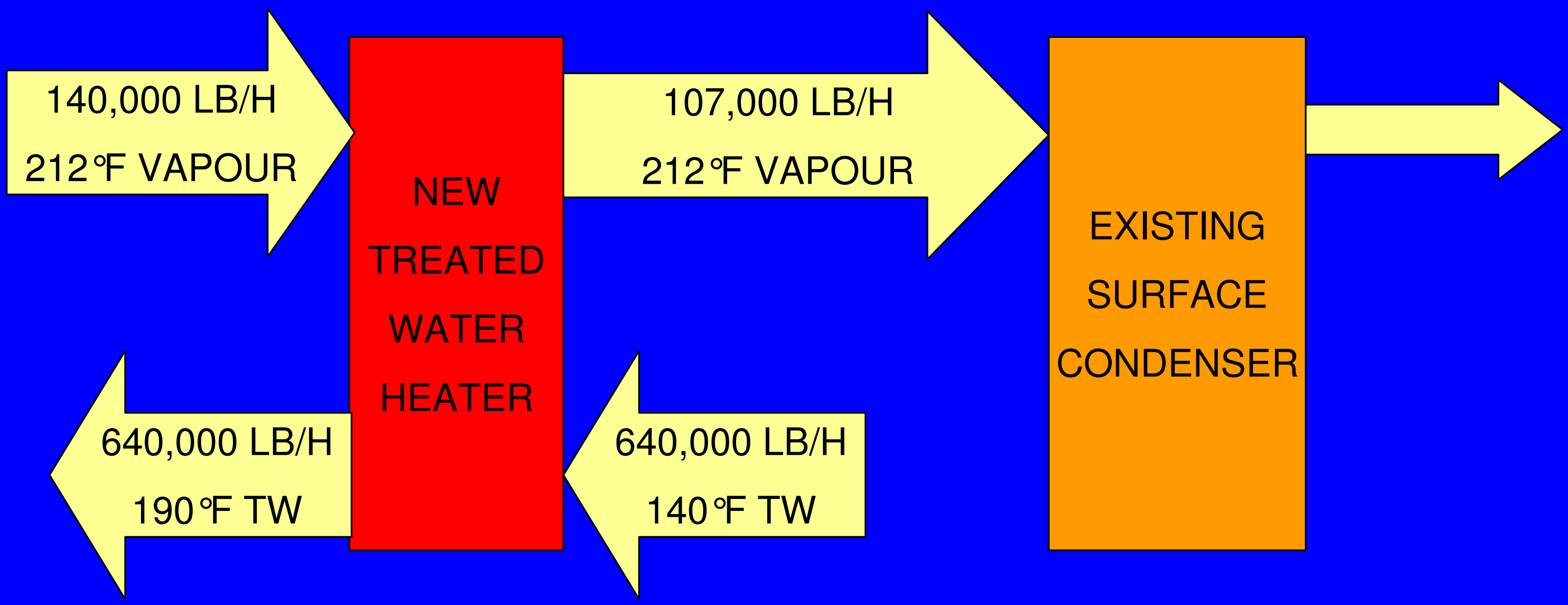
HEAT EXCHANGER EVALUATION – CASE STUDIES

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

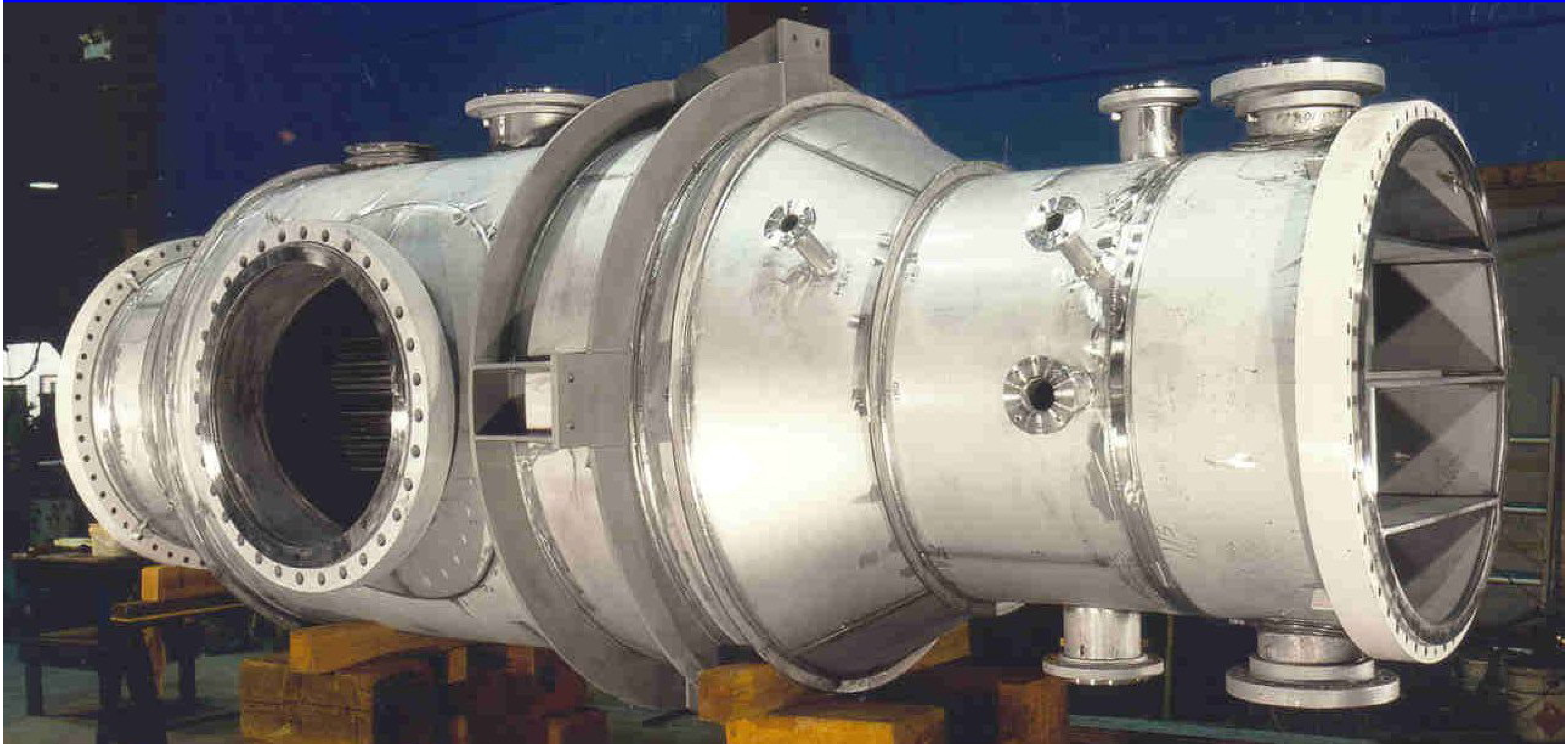


SC ADDITION
– KEY DESIGN ISSUES

- 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

- $Q = 32$ MM BTU/H — $A_o = 4008\ FT^2$, 1 SHELL
- 6 TUBE PASSES — PD = 5.8 PSI

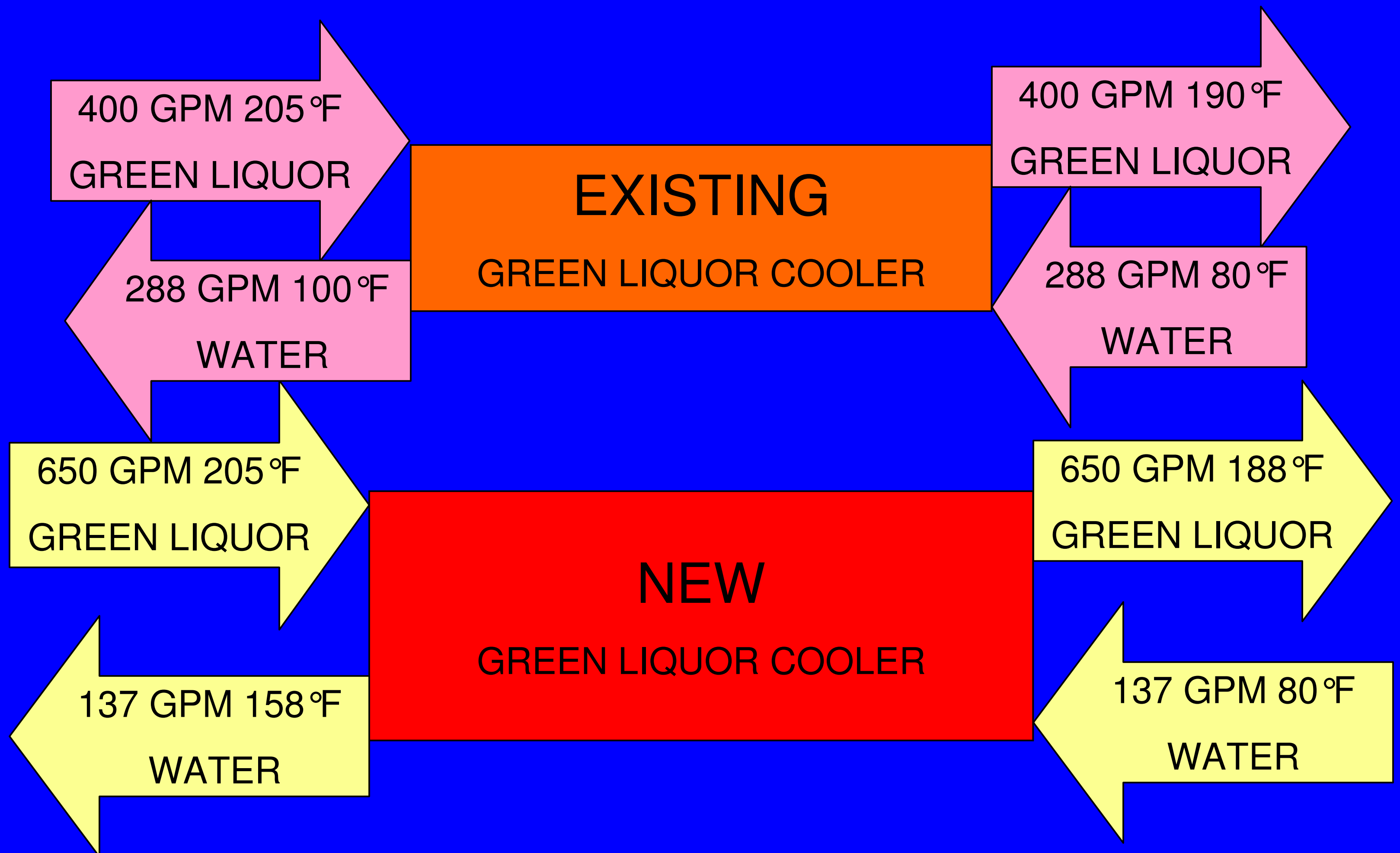


2. GREEN LIQUOR COOLER REPLACEMENT

ISSUES

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

GLC REPLACEMENT - FLOWSHEET



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

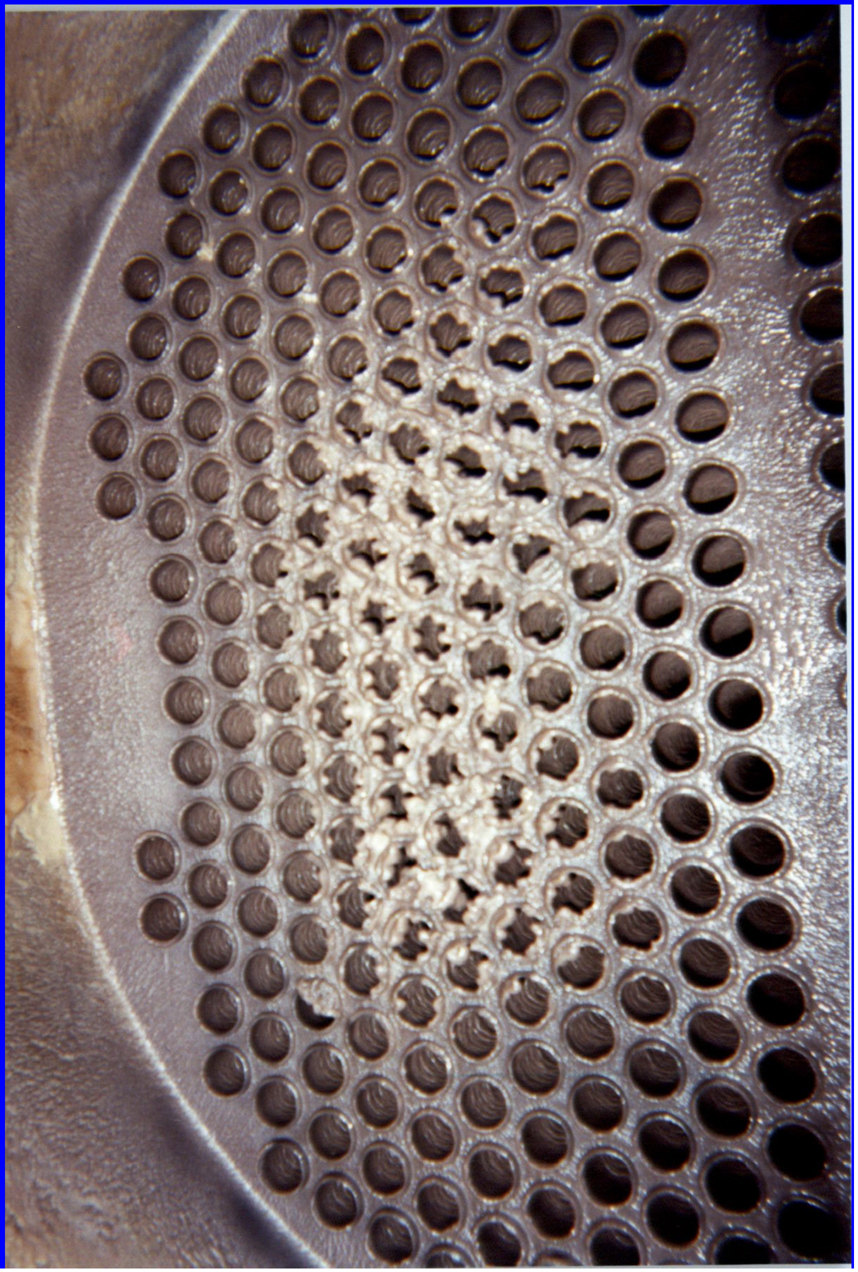
GLC REPLACEMENT - RESULTS

	NEW	EXISTING
Q MMBTU/H	5.3	2.8
AREA FT^2	553	144
TUBES	1" x 18 BWG	5/8" x 18 BWG

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

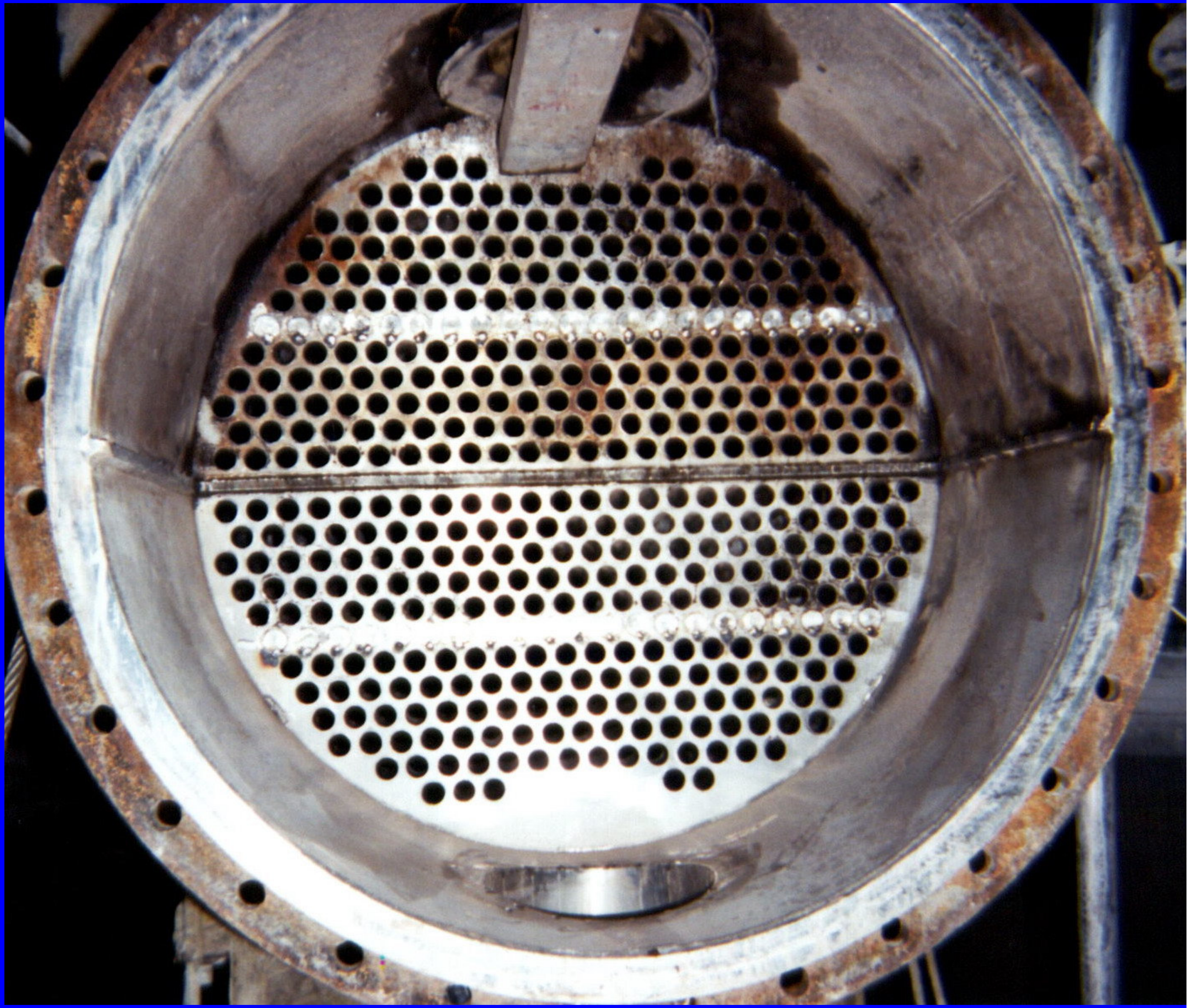
- REDUCE FOULING → MINIMUM VELOCITY 3 FPS REQUIRED, CONVERT ALL 4 SHELLS FROM 2 PASSES TO 4 PASSES
- ADDING 2 CHANNEL PARTITION PLATES → LOSS OF SURFACE AREA (42 TUBES)
- UNEVEN TUBES PER PASS → 10% DIFFERENCE
- HIGHER PRESSURE DROP → EXISTING PUMP OK
- WORK COMPLETED DURING SHUTDOWN

STRIPPER PREHEATER RECONFIGURATION-RESULTS

	BEFORE	AFTER
TUBE PASSES	2 x 230 TUBES	4 x 104.5 TUBES
TUBE VELOCITY FPS	1.9	4.2
LOSS OF HEAT TRANSFER	WITHIN 2 WEEKS	SHUTDOWN: TUBES ARE CLEAN
TUBE SIDE DELTA P PSI	4.0	18.8
CLEANING	MONTHLY	BI-ANNUALLY

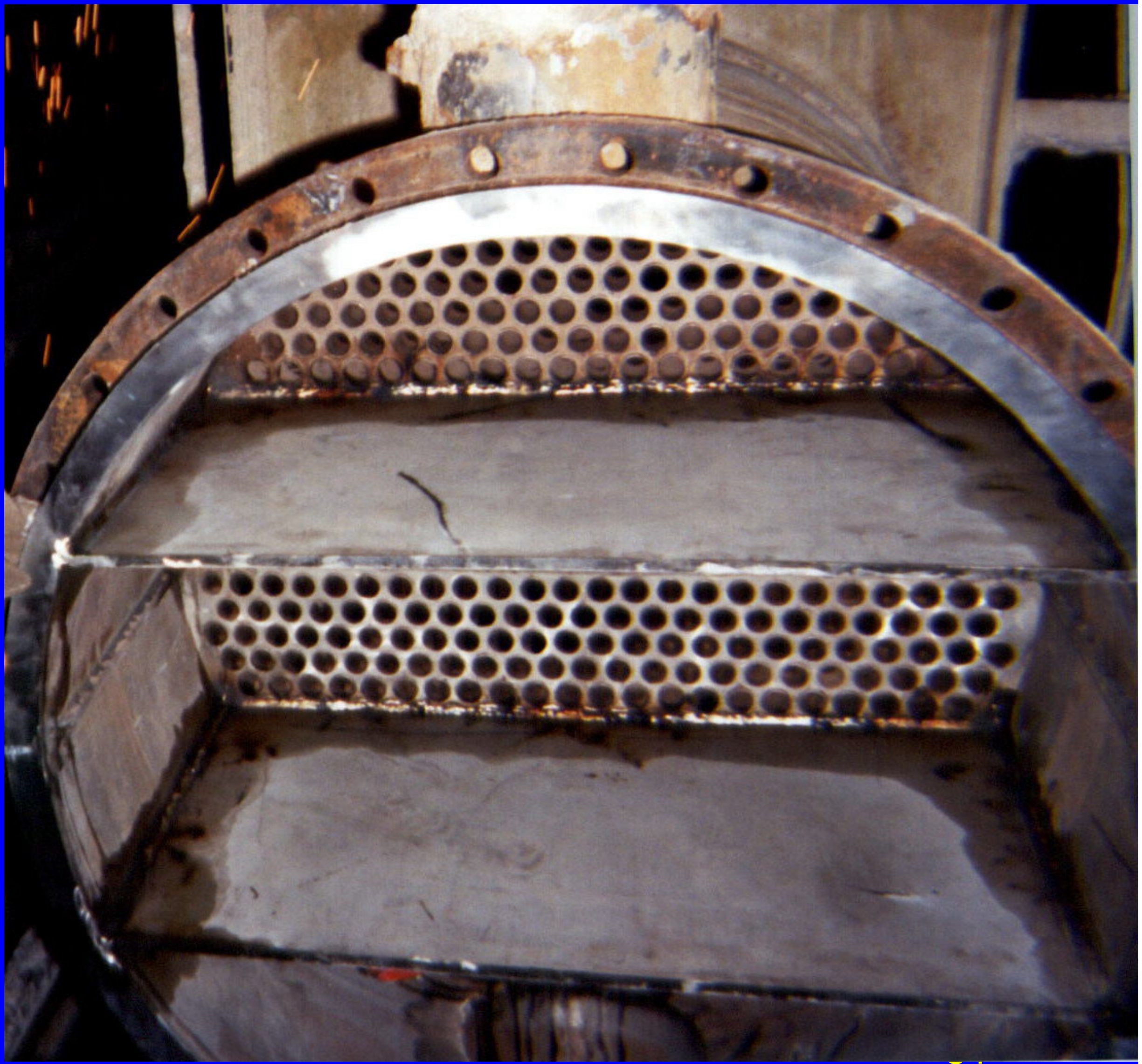
STRIPPER PREHEATER RECONF'N

- 2 ROWS OF TUBES PLUGGED OFF



STRIPPER PREHEATER RECONF'N

- TWO PARTITION PLATES ADDED



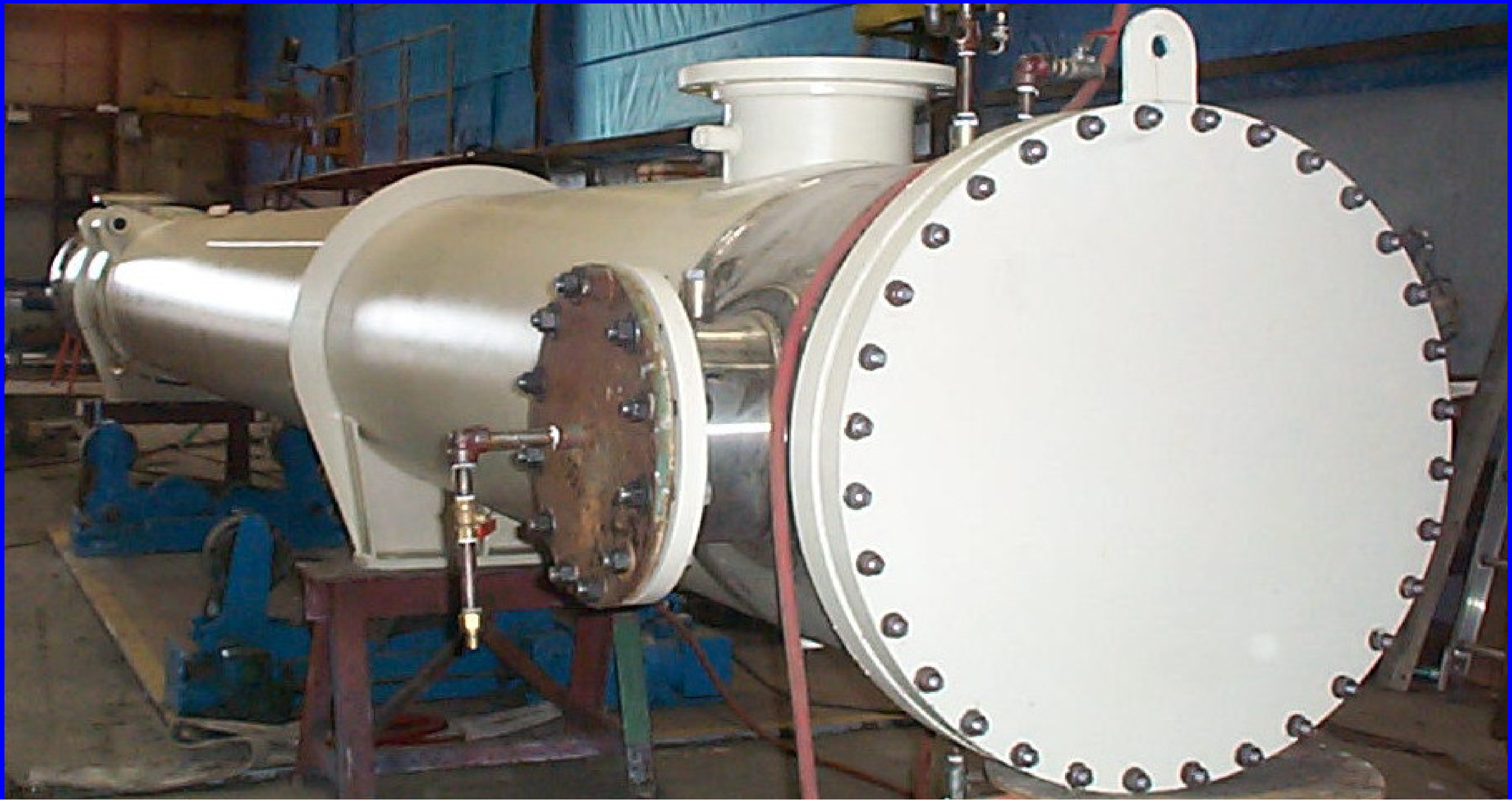
4. LIQUOR COOLER AUGMENTATION

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

- UNDERSIZED 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

	AFTER – 2 UNITS	BEFORE – 1 UNIT
AREA FT^2	2930 +4172 =7101	2930
Q MMBTU/H	96.9	65.8
MTD CORR FACTOR	0.973 / 0.950	0.972
WATER	2640 GPM, 125 → 200°F	1780 GPM, 41 → 111°F
LIQUOR	2700 GPM, 280 → 205°F	2700 GPM, 252 → 200°F

LIQUOR COOLER AUGMENTATION

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

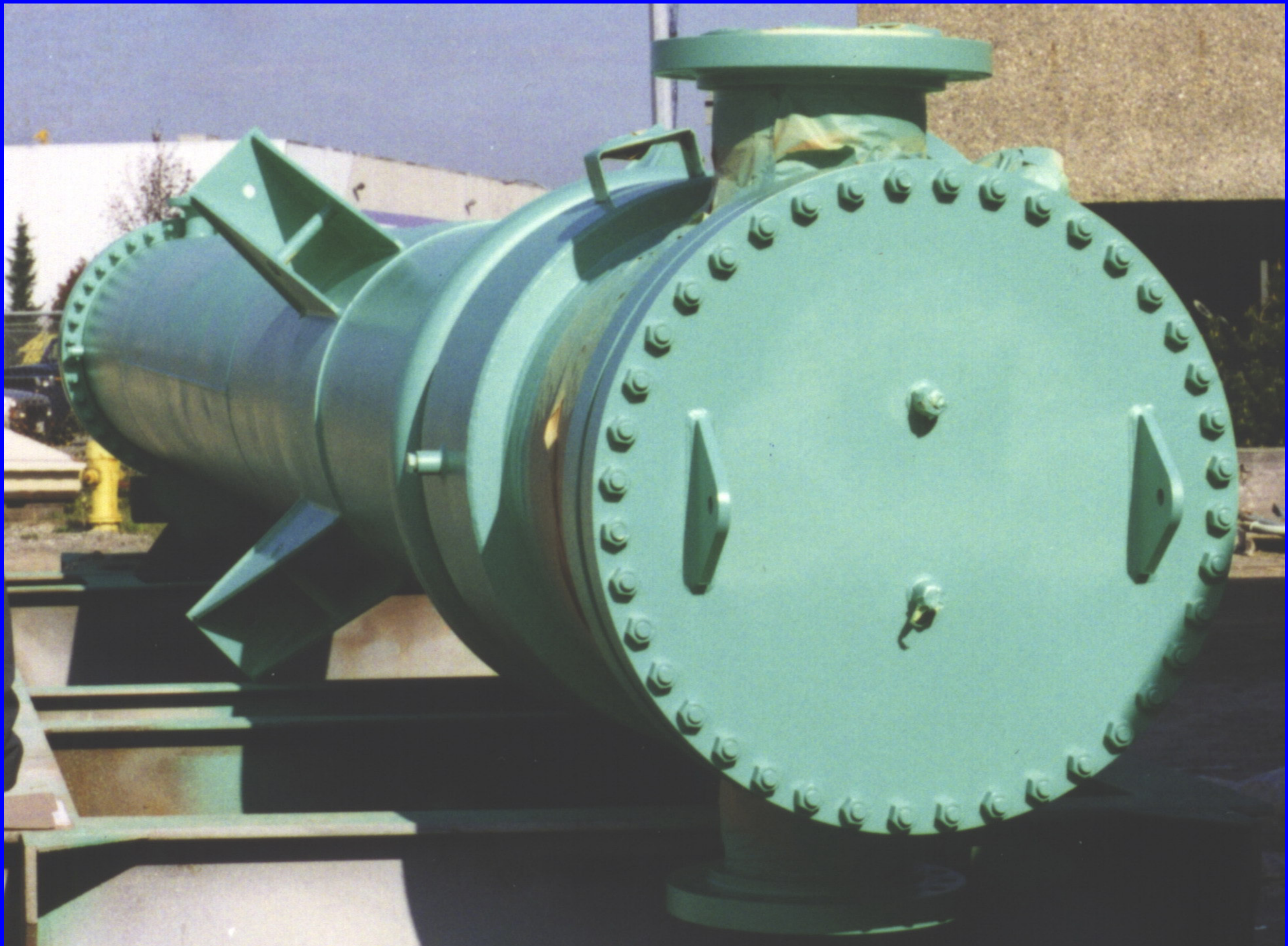
LIQUOR HEATER REPLACEMENT – KEY DESIGN ISSUES

- 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

	NOW	ENGINEERING PHASE
AREA FT^2	1,664	1,675
TUBES	360 – 1.25”x16 BWG x 15’-9”	238 – 1.25”x16 BWG x 24’
TUBE VELOCITY FPS	5.4	8.2
TUBE SIDE DELTA P PSI	3.1	8.5

DIGESTER LIQUOR HEATER REPLACEMENT



6. BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER

ISSUES

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

BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - FLOWSHEET

BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - HEAT DUTY Q

m = 2300 gpm *500.7 lb/h /gpm *0.981

= 1,130,000 lb/h

BY ITERATION, ASSUME t_2 = 124.3°F

Q_{EFFL} = 1,130,000 * 1 *(170 – 124.3)

= 51.6 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

$A = Q / (U_O \Delta t)$

$= 12{,}030$ ft^2, SO CHECKS!

BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - PRESSURE DROPS & VELOCITIES

- ΔP_T = 4.0 PSI
- ΔP_S = 9.8 PSI
- TUBE VELOCITY V = 3.3 FPS

BLEACH CAUSTIC EFFLUENT HEAT EXCHANGER - RESULTS

AREA FT^2	2 SHELLS x 6016	
Q MMBTU/H	51.6	
WATER	1160 GPM, 70 → 160°F	
LIQUOR	2300 GPM, 170 → 124°F	

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

AHL

QUESTIONS?

COMMENTS?

2/4/2007