Micro Tube Heat Exchangers for Power Plant Condensers

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Background: Logic for talk

1. I've never designed a condenser for a power plant, and I am not currently doing business in this field.
2. I didn't have time to really evaluate what alternatives are currently being examined.
3. Mezzo Technologies makes micro tube heat exchangers. The heat transfer/air pressure drop ratio of these heat exchangers is higher than the competition that Mezzo has been able to identify (aluminum plate-fin for example). This attribute seems important for air-based condensers.
4. For two-phase-water, micro tube heat exchangers also seem to give very good performance.
5. The problem definition for a condenser that dumps heat to the ambient air seems reasonably simple to this non-expert in the field:
   - Provide sufficient heat transfer
   - Minimize fan power required to pull air through the heat exchanger.
   - Minimize Initial cost, footprint, and maintenance costs.
6. The problem definition for a condenser that uses water is less well understood. The following assumptions were used to define a "high performance" steam condenser for low water availability applications:
   - Minimize water flow rate (maximize exit temperature of water).
   - Minimize cost of condenser.
   - Provide design that is robust and easily maintained.

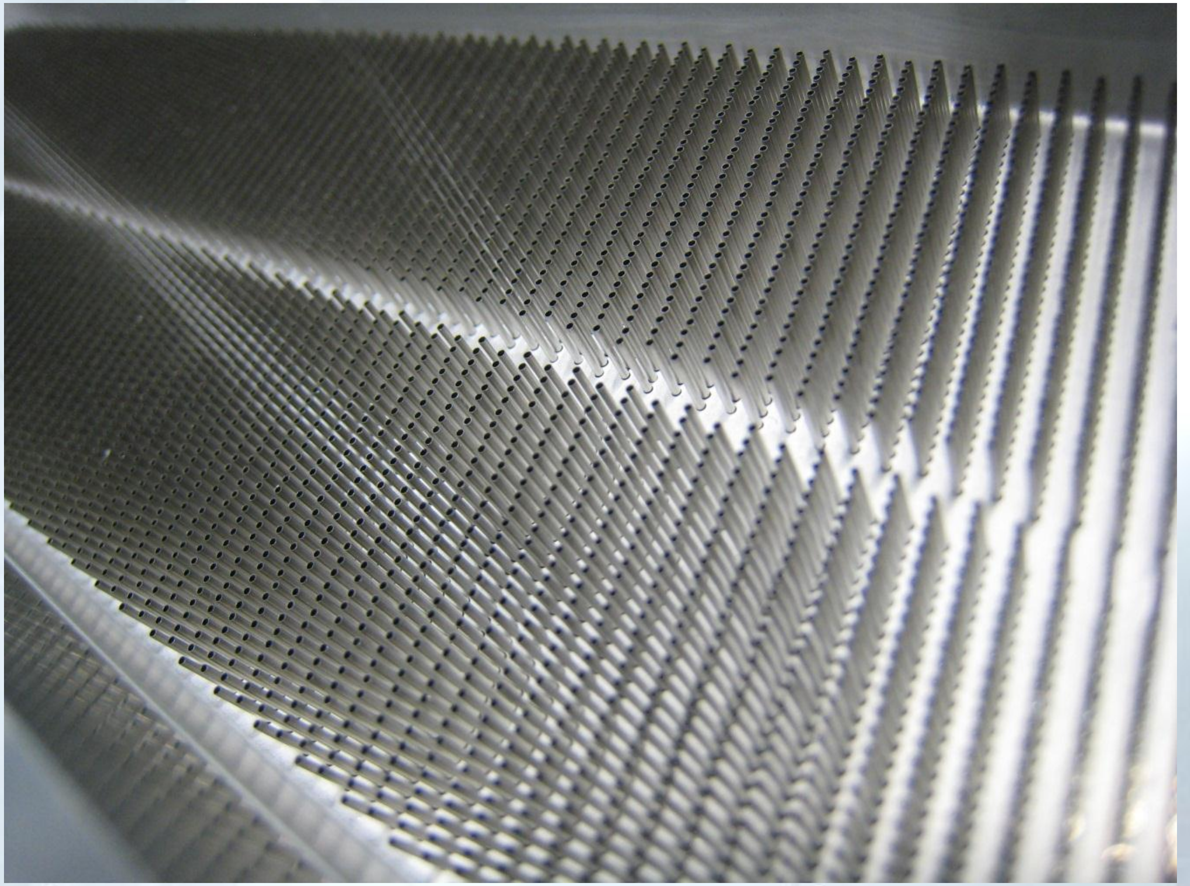
Snapshot of Mezzo

- Manufacture high performance micro tube heat exchangers (radiators, condensers, evaporators, oil coolers, recuperators etc.)
- Revenue: 70% SBIR, 30% Commercial
- 12 employees
- Located at the Bon Carre Business Park, Florida Boulevard, Baton Rouge

Micro Tube Heat Exchangers

Mezzo micro tube heat exchangers:

- Proprietary tube bank correlations with high performance.
- Cost effective methods to assemble and join (via epoxies or braze) tens of thousands of tubes to headers.
- Patent protection on methods to make micro tube heat exchangers.



Micro Tube Heat Exchangers

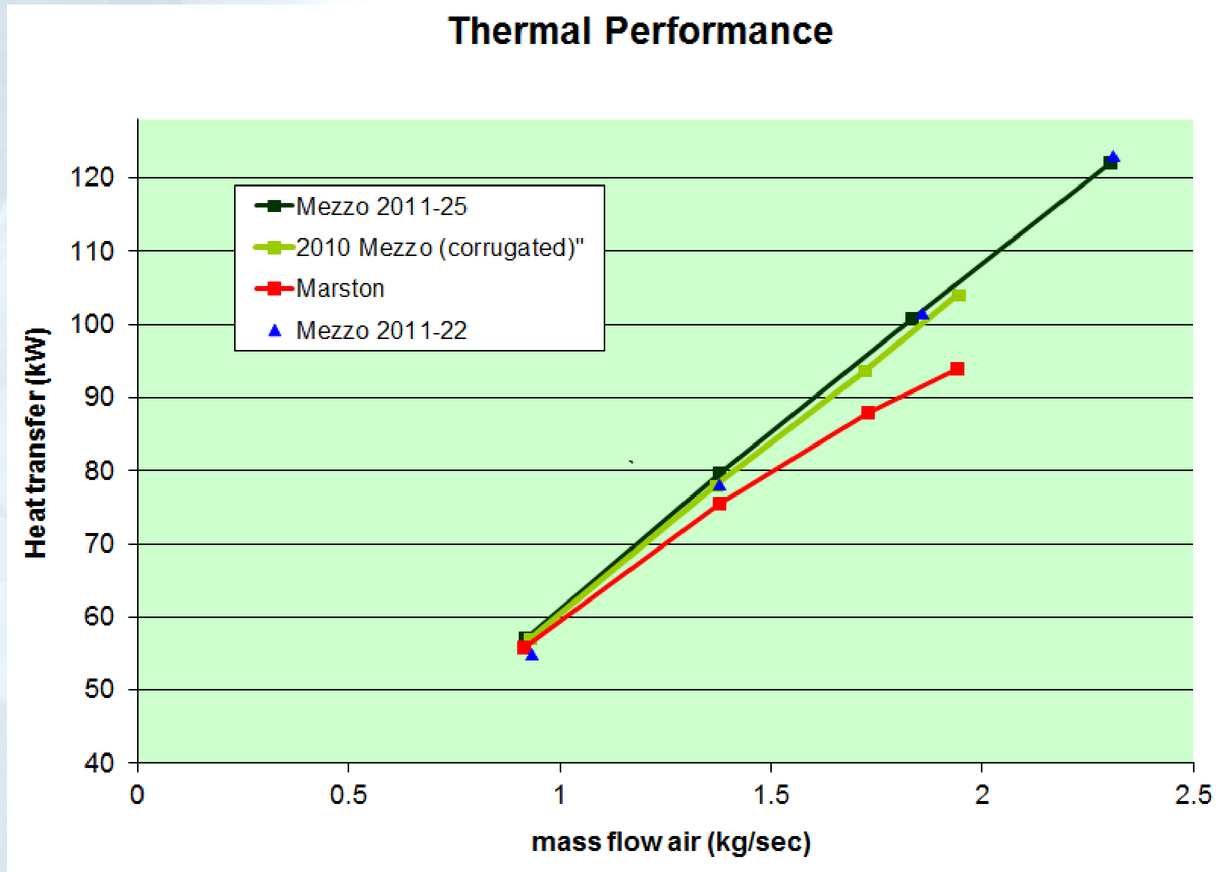
Indy radiator:

- Most teams used Mezzo radiators in 2010 and 2011.
- In back-to-back tests, using Mezzo rad reduced engine temperature 6-8 C.
- Mezzo UA/air pressure drop about 30-40% higher than high performance aluminum plate-fin.
- Very robust: Some teams used single radiator the entire season.

Micro Tube Heat Exchangers

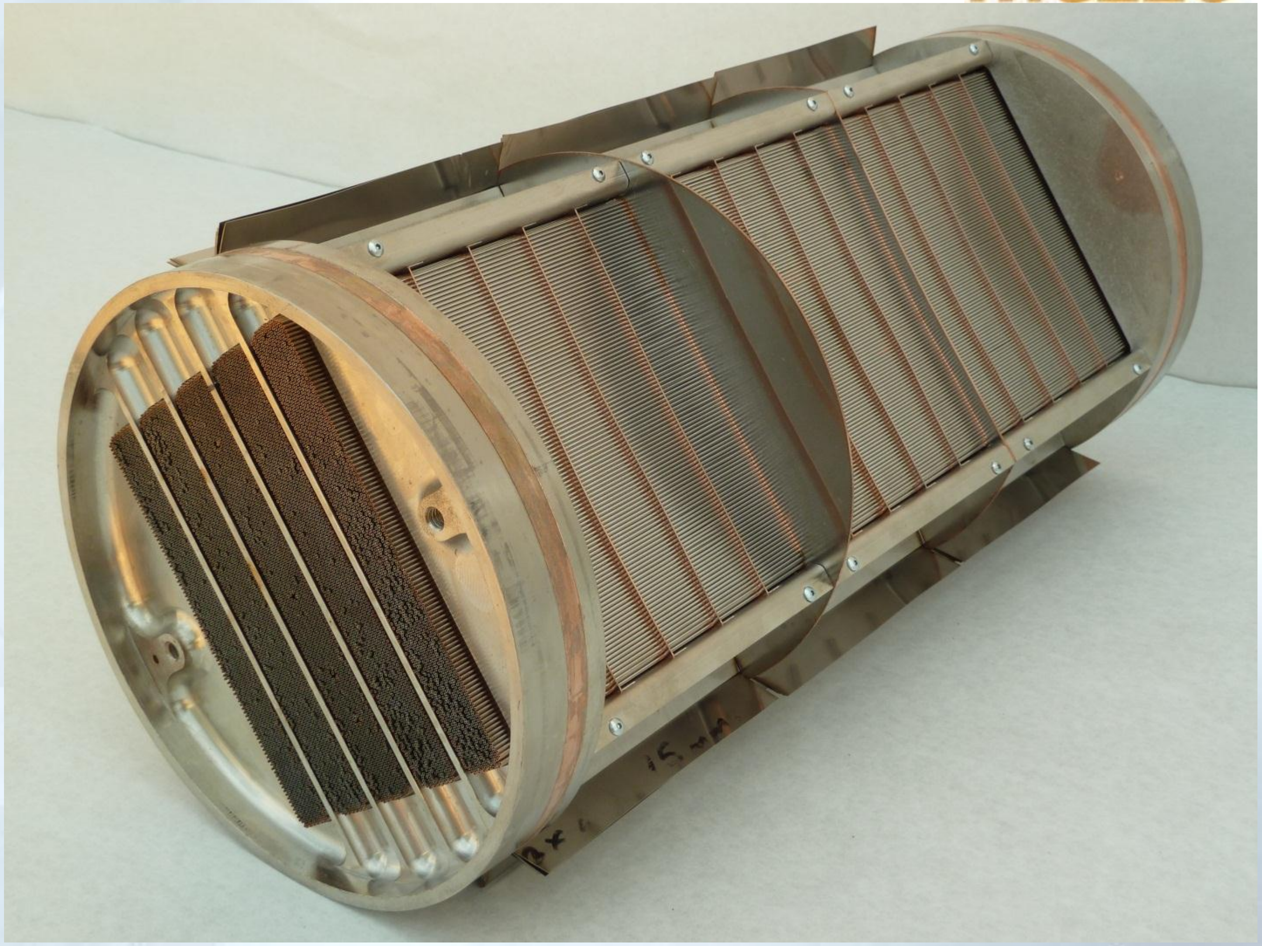
Indy radiator:

- Comparison of heat transfer shows significant improvement.
- Air side pressure drops (in this test) were the same.
- UA increase associated with Mezzo: 30-50%



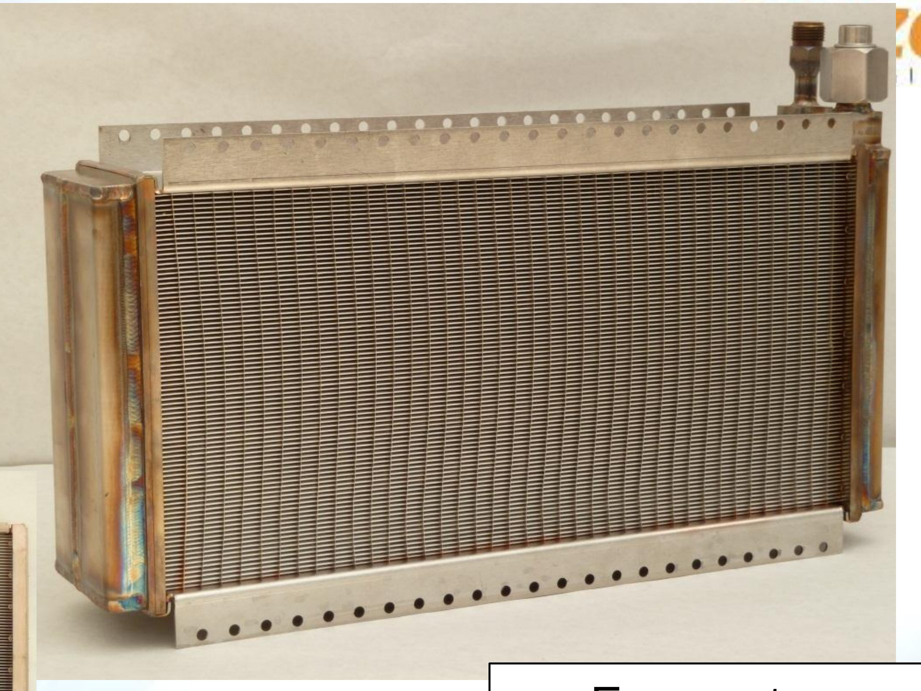
Economizer:

- Navy SBIR program.
- Proof pressure: 1000 psi.
- Incorporates advantages of shell-and-tube design.
- About 1/3 volume, 1/3 weight of brazed plate alternative.
- Potential to produce for lower cost!

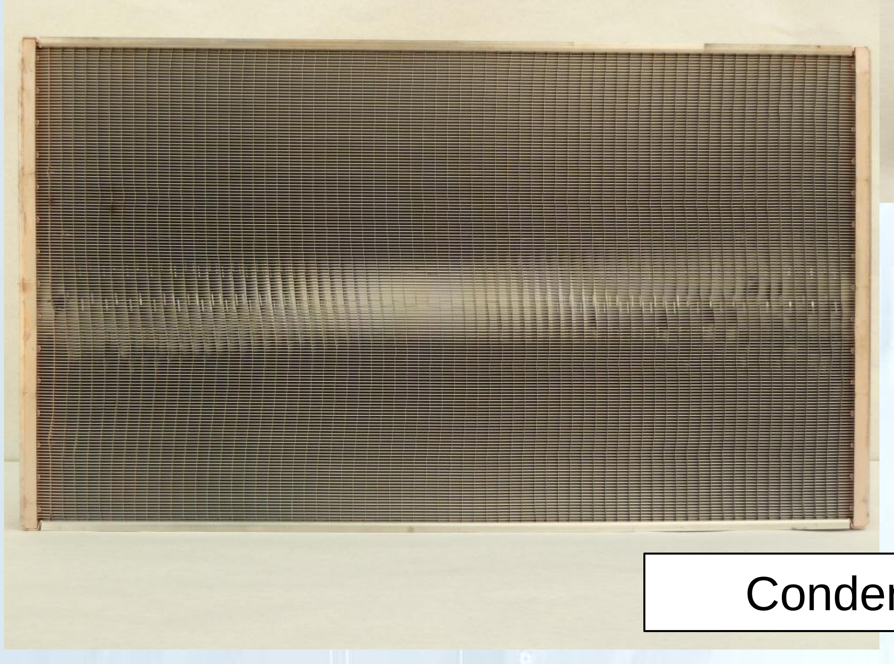


Condenser/evaporator for Bradley Fighting Vehicle:

- Army SBIR program.
- Proof pressure: 1000 psi.
- Incorporates advantages of shell-and-tube design.
- More heat transfer/lower air side pressure drop.



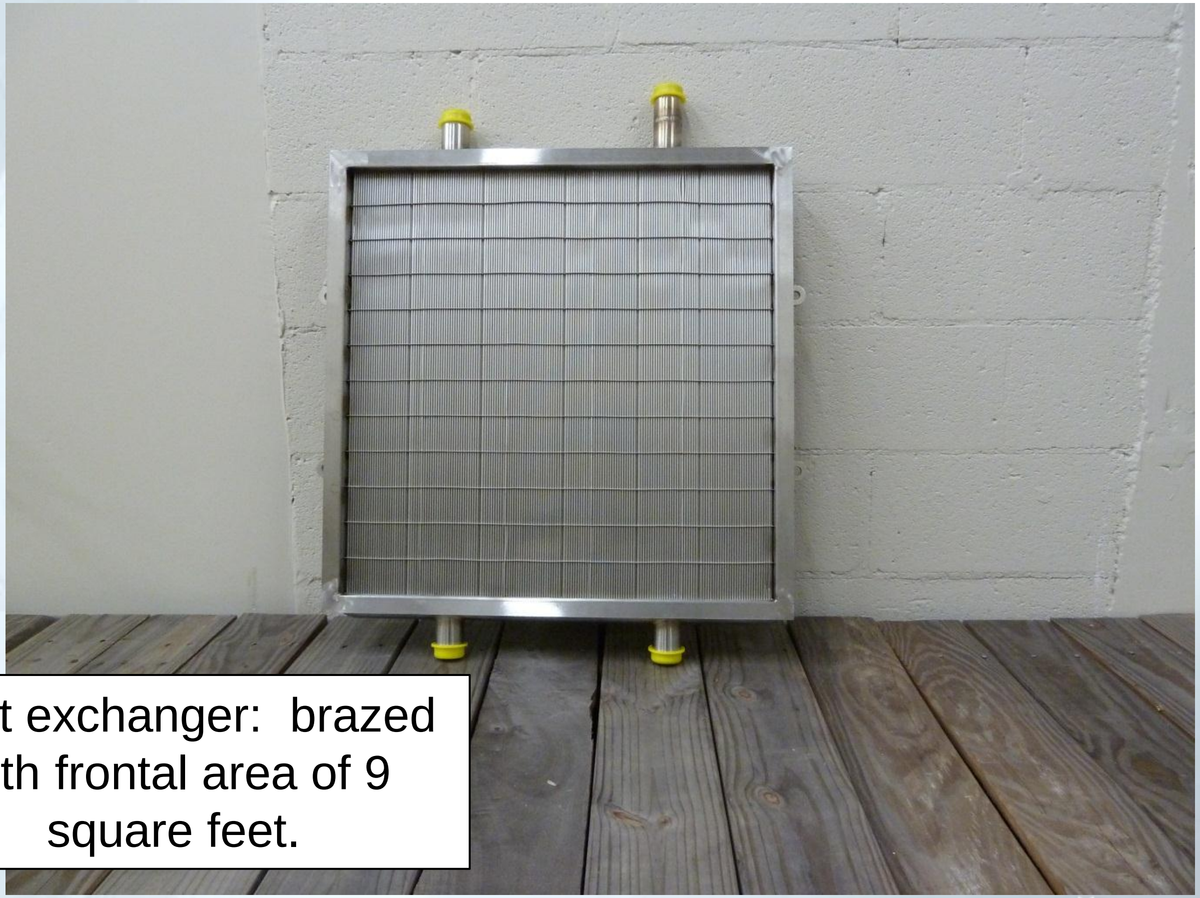
Evaporator



Condenser

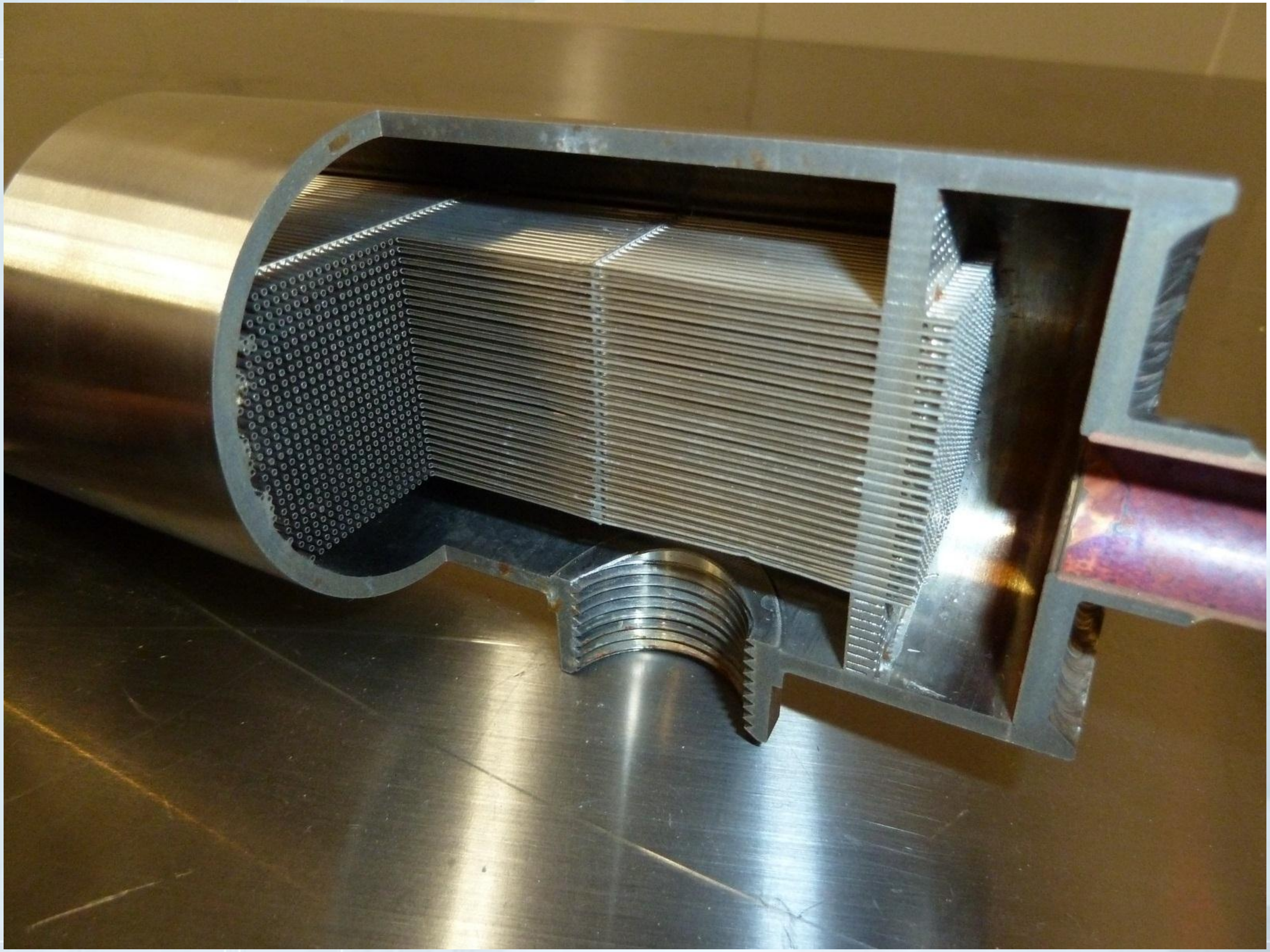
Oil and gas application:

- High heat transfer with low air side pressure drop.
- Thousands of 3 foot x 3 foot modules required.
- Economic advantage over existing plant design.



Heat exchanger: brazed with frontal area of 9 square feet.

High Pressure shell-and-tube with microtubes:
Refrigerant through tubes, water on the shell side



Air-based Condenser Specifications

ESKOM's Matimba (6 units: 680 MW each)

Dry air-based condenser

- Heat transfer: 780 MW
- Steam condensing temp: 150 F
- Ambient air temp: 80 F
- Air flow rate: 24,000 kg/sec
- Air volume flow rate: 1.24 x 10^6 m^3/min

Solution #1 (80 F day)

- 699 modules each 15 feet x 5 feet x 4.85 inches deep (39 x 10^6 tubes)
- Air exit temp: 138 F (83% effectiveness)
- Air pressure drop: 1.13 mbar
- Air power requirement (fan efficiency= 90%): 2.6 MW (about 1% of plant power).
- Tube cost: $7M
- Tube mass: 280 tons
- Tubes: SS with OD = .050 inches, ID = .038 inches

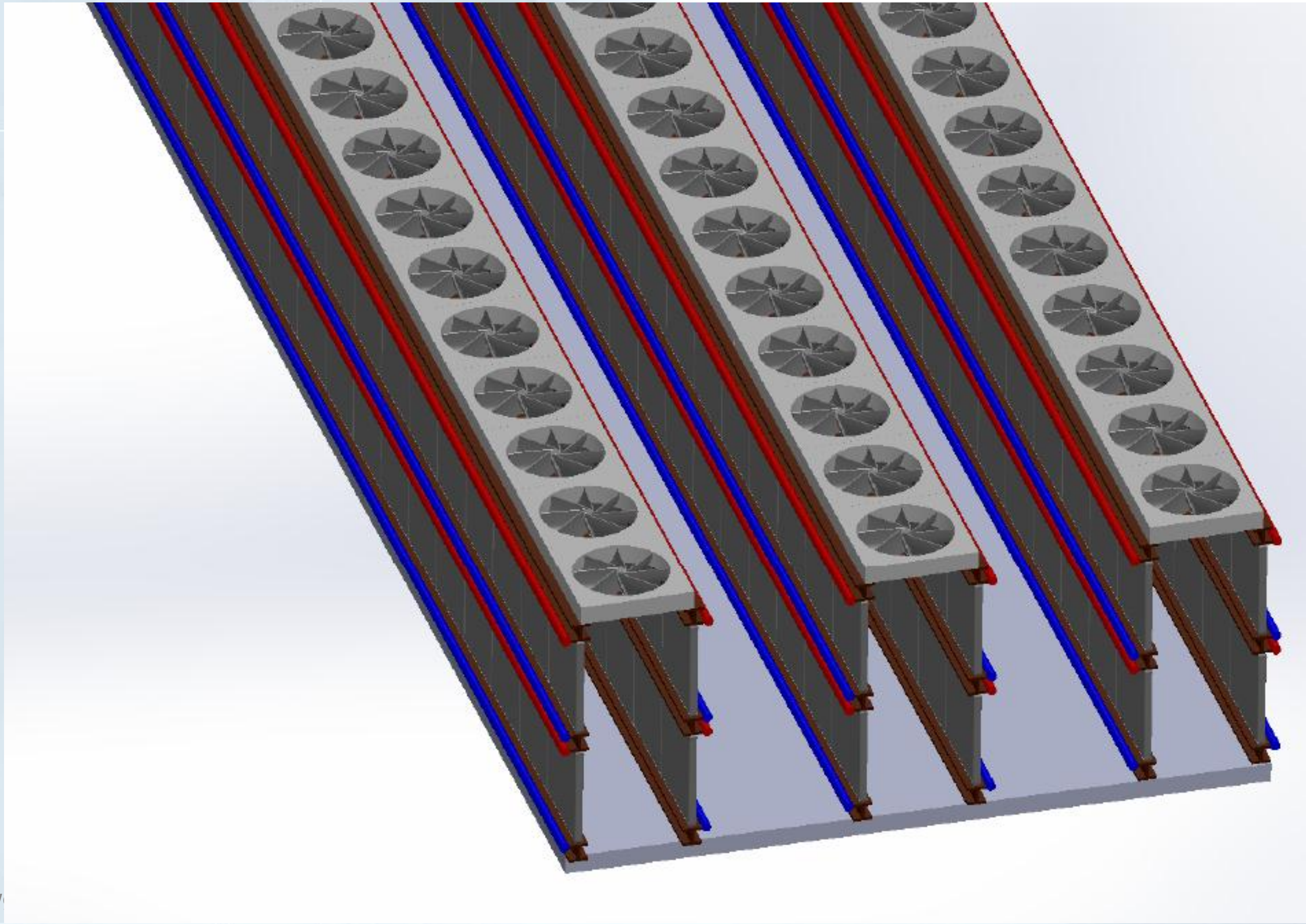
Dry air-based condenser: hot day (100 F)

- Heat transfer: 780 MW
- Steam condensing temp: 150 F
- Ambient air temp: 100 F
- Air flow rate: 36,000 kg/sec
- Air volume flow rate: 1.92 x 10^6 m^3/min

Solution

- 699 modules each 15 feet x 5 feet x 4.5 inches deep.
- Air exit temp: 138 F (83% effectiveness)
- Air pressure drop: 2.41 mbar
- Air power requirement (fan efficiency= 90%): 7.7 MW (about 3.1% of plant power).
- Tube cost: $6.3M
- Tube mass: 280 tons
- Tubes: SS with OD = .050 inches, ID = .038 inches

Schematic of Plant



FLUID CONDITIONS

Quantity	FLUID 1 (Tube side) Value	Unit	FLUID 2 (Shell side) Value	Unit
Flow Rate	60000.00	kg/s	36000.00	kg/s
Inlet Temperature	150.00	ºF	100.00	ºF
Inlet Pressure (absolute)	30.00	psi	14.70	psi
Allowable Pressure Drop	0.00	psi	0.00	mbar
Fluid Name	Water (Incropera)		Air (Incropera)	

	Value	Unit
Heat Load	**781000.0**	kW

Heat Load Desired Value Should Be Iterated to Match Heat Load Actual Value in The Output Table

HEAT EXCHANGER GEOMETRY

Width		10500.00 ft
Length (flow length of Fluid 2)		4.85 in
Height (exposed tube length)		5.00 ft
Tube Bank Arrangement		In-Line
Tube Wall Thickness		6 thou
Tube Outer Diameter		50 thou
Relative Longitudinal Spacing (S_L/D_o)		[redacted]
Relative Transverse Spacing (S_T/D_o)		
Tripped tube flow (Yes/No)		Yes
Number of Sub-Laminates (stacked along the height)		1
Multipass Configuration	*Flow*	Shell side
	Number of Passes	1
Extra Tube Length for Joining (total)		0.5 in
Fluid Port Inner Diameter *(enter size & units or ZERO if intake is face area)*		
	Tube Side	0 in
	Shell Side	0 in

		FLUID 1 *(tube side)*		FLUID 2 *(shell side)*	
Fluid Name		Water (Incropera) Cmax		Air (Incropera) Cmin	
Mass Flow Rate		3600000.000	*kg/min*	2160000.000	*kg/min*
Inlet Volumetric Flow Rate		3672.798	*m3/min*	1919415.657	*m3/min*
Standard Volumetric Flow Rate		N/A	*N/A*	63578022.833	*SCFM*
Temperature	*Inlet*	150.00	*ºF*	100.00	*ºF*
	Average	147.20	*ºF*	119.37	*ºF*
	Exit	144.40	*ºF*	138.75	*ºF*
Pressure Drop	*Allowable*	0.000	*mbar*	0.000	*mbar*
	Total	1403.279	*mbar*	2.416	*mbar*
	Channels only	1403.279	*mbar*	2.416	*mbar*
	Minor losses	0.000	*mbar*	0.000	*mbar*
Dynamic Press	*Inlet duct/pipe*	0.118	*mbar*	0.242	*mbar*
Porosity *(% open area)*		7.3	*%*	75.9	*%*
Number of Channels		39,267,469.9		607,228.9	
Hydraulic Diameter		0.965	*mm*	1.270	*mm*
Channel Aspect Ratio				769.036	
Flow Type		Turbulent			
Heat Capacity		251211626.144	*W/K*	36283234.067	*W/K*
Velocity	*inlet Manifold/Duct*	0.16	*m/s*	6.56	*m/s*
	inside Channels	2.13	*m/s*	8.93	*m/s*
Re		4593.5		633.8	
f (or effective f)		0.04		0.086102	*per row*
Nu		26.5		11.433008	
h convection		18042	*W/K-m2*	251	*W/K-m2*
Thermal Conductance		3273909193	*W/K*	59980709	*W/K*

Total Width		126000.00	*in*
Total Length	*Fluid 2 flow direction*	4.85	*in*
Face Area	*Fluid 1*	611100.00	*in2*
	Fluid 2	7560000.000	*in2*
Volume		21218.75	*ft3*
Mass	*dry w/ extra tube length*	562347.274	*lb*
	wet w/ extra tube length	657053.719	*lb*
ΔT_{inlet} Fluids		50.00	*ºF*
Cr		0.144	
Effectiveness	*desired*	77.49	*%*
	actual	76.77	*%*
NTU	*required*	1.66	
	provided	1.62	
UA	*required* *without safety factor*	60105567.68	*W/K*
	required *if single pass*	60105567.68	*W/K*
	required *with safety factor*	60105567.68	*W/K*
	provided	58733252.08	*W/K*
Heat Load	*desired*	781000.000	*kW*
	actual	773773.170	*kW*
Tube bank Arrangement		In-Line	
S_L/D		[redacted]	
S_T/D			
S_L			*mm*
S_T			*mm*
Number Tube Rows			
Number Tube Columns			
Number Tubes Total			
Transverse Gap			*mm*
Longitudinal Gap			*mm*

Water-based condenser

- Heat transfer: 3,000,000 kW
- Steam condensing temp: 160
- Water temp: 95 F
- Water flow rate: 25,000 kg/sec
- Water exit temp: 146 F (effectiveness of 78%)
- Core size: W = 50 feet, Tube length = 5 feet, Tube bank depth = 5 feet
- Tube OD = .150 inches
- Tube Wall = .010 inches
- # Tubes = 603,000
- Tube cost= $300k

Final thoughts

- Micro tube heat exchangers can offer, in certain arrangements, excellent ratios of heat transfer/air side pressure drop. This reality may be of use for ACC.
- Water cooled condensers might be more compact using "small" micro tubes.
- Whether these concepts have commercial potential to be determined.
- Some might be skeptical that heat exchangers with millions of small tubes can be dependable. I think that such heat exchangers can be fabricated, and they will be dependable.
- Thanks for inviting me.