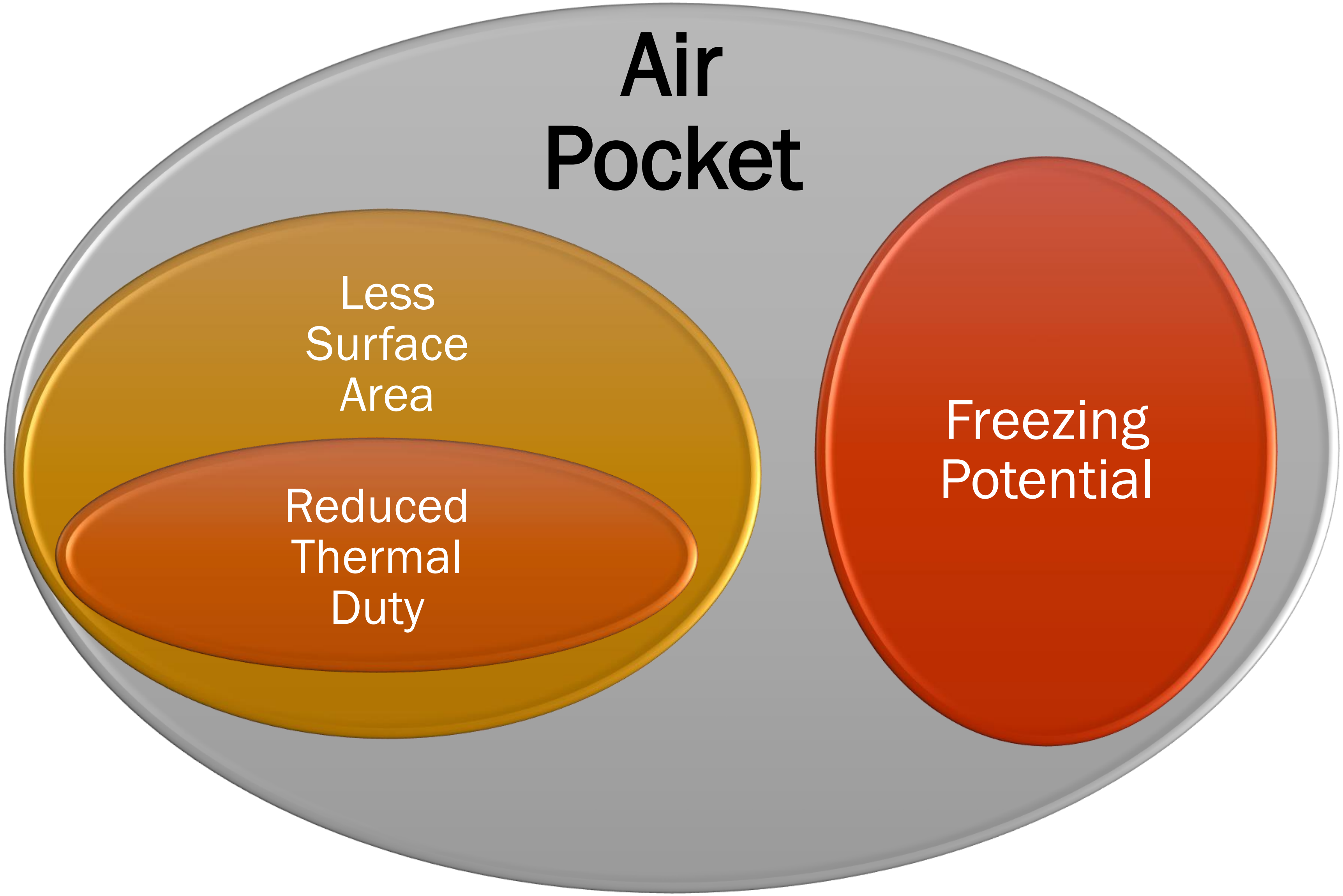
Air Pockets in ACC Tubes

Causes, Effects & Prevention

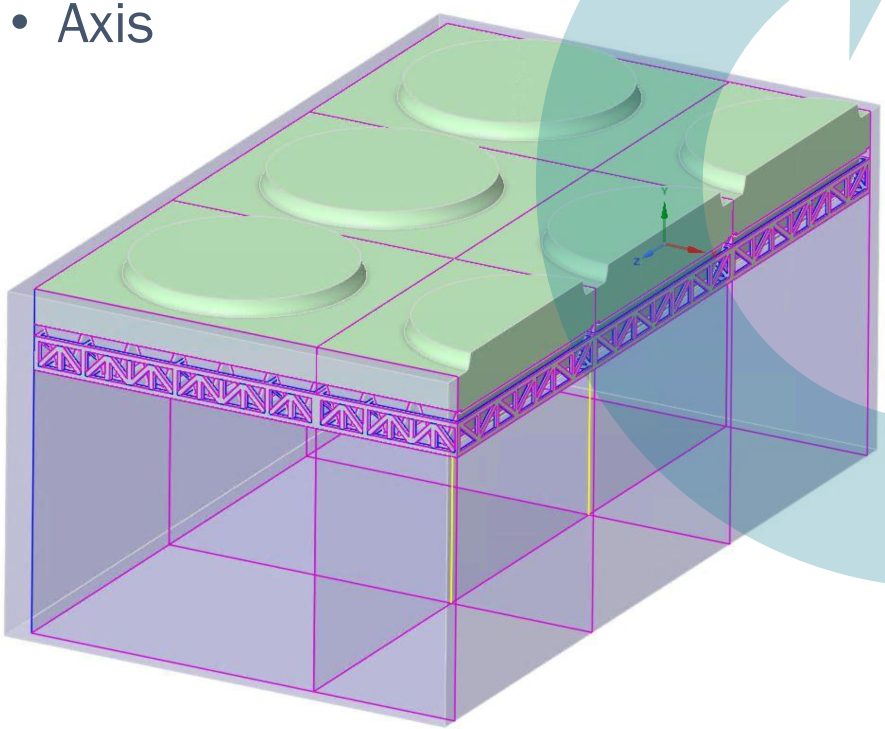

Air
Pocket
Less
Surface
Area
Reduced
Thermal
Duty
Freezing
Potential

evapco Dry Cooling

Evapco Dry Cooling R&D

- Computer Modeling Tools
  - Fluent
  - Arrow
- Evapco's In House Rating software
  - Axis

- Environmentally controlled test chamber for ACHE testing
- Full size bundles tested in real life conditions with steam under vacuum
- AT-ACC Test Cell

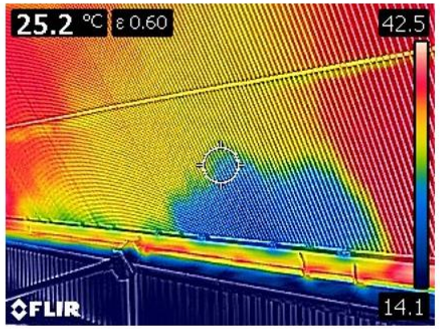


Air Pockets in ACC Tubes

Air pockets in ACC tubes

causes

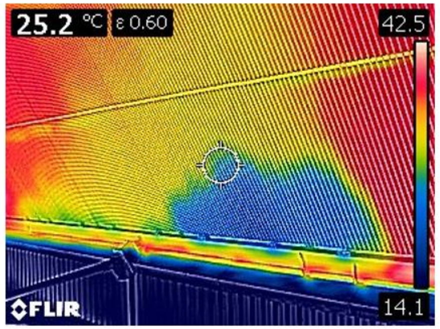
- Backflow
- Vacuum System Performance
- Excessive saturated oxygen
- Excessive Air Ingress



Air Pockets in ACC Tubes

effects

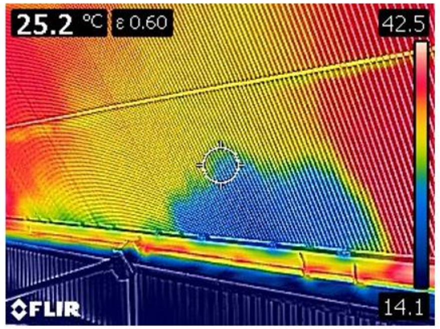
- performance reduction
- freezing risk



Air Pockets in ACC Tubes

prevention

- auxiliary equipment sizing
- minimize air in-leakage
- ACC design



Air pockets in ACC tubes

causes

- Backflow
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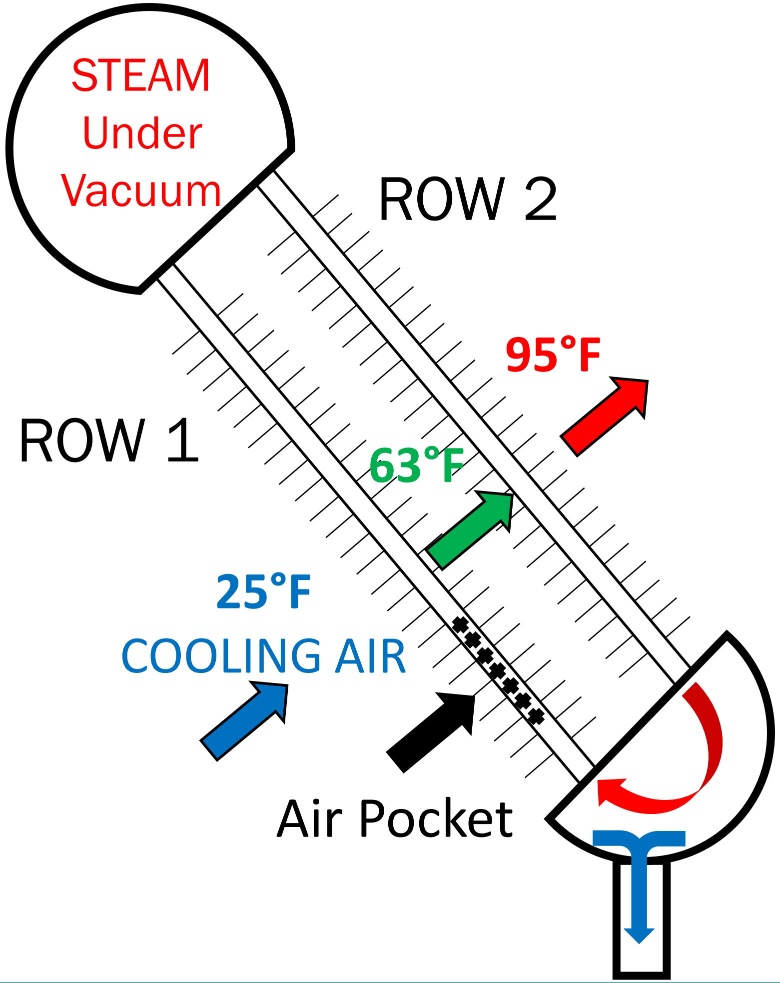
causes: backflow

what is backflow?



multi row tube

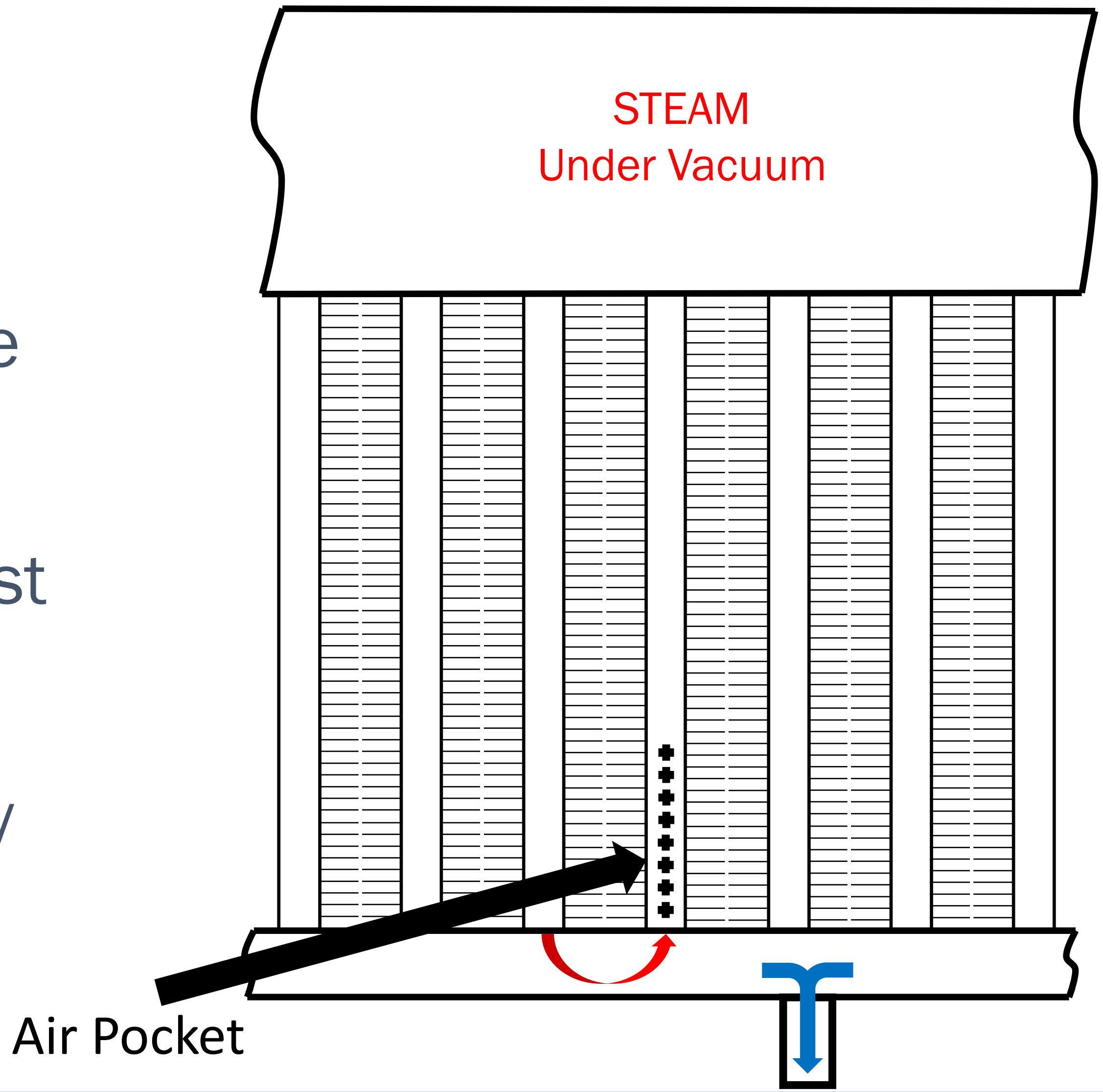
- Tube closest to fresh air performs the best
- Low pressure regions created
- Steam flows to low pressure region pushing back against steam attempting to flow down
- Air pockets build up
- Steam condenses, but air is left behind

causes: backflow

what is backflow?

single row tube

- Low pressure regions can be created in single row tube bundles
- Higher performing tubes exist in areas of concentrated air flow
- Lower performing tubes may exist at cell corners



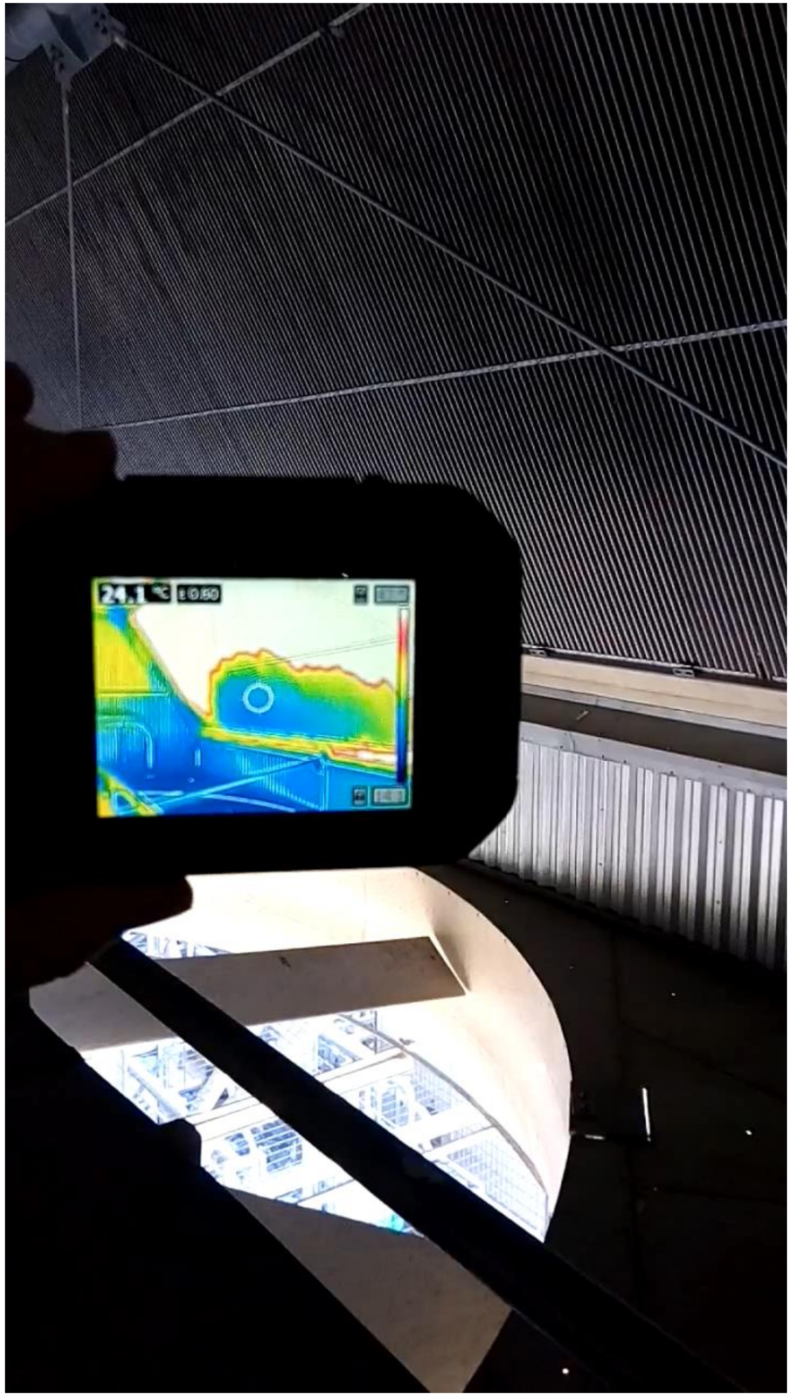
causes: backflow

A-Frame ACC backflow

Air pockets are visible in cold section of bundle (blue color)

Hot tubes filled with steam show as red or white color

When fan is turned off air pocket disappears



causes: backflow

A-Frame ACC backflow

Air pockets are visible in cold section of bundle (blue color)

Hot tubes filled with steam show as red or white color

When fan is turned off air pocket disappears

causes: backflow

summary

- Capacity differences in the ACC tubes lead to back flow
- Capacity differences are generally from air velocity differences or air temperature differences at the face of the bundle
  - Air temperature: multi row tube
  - Air velocity: A-Frame cell with fan ON vs cell with fan OFF
- **Air pockets form in the higher capacity tubes**
  - **Higher capacity = lower relative air temperature or higher relative air velocity**

causes: vacuum system performance

no ACC is 100% leak tight → vacuum systems are necessary

SCFM	3.0	4.0	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5
Steam Flow (lb/hr)	0 - 25,000	25,001 - 50,000	50,001 - 100,000	100,001 - 250,000	250,001 - 500,000	500,001 - 750,000	750,001 - 1,000,000	1,000,001 – 1,250,000	1,250,001 – 1,500,000	1,500,001 - 2,000,000	2,000,001 - 2,500,000	2,500,001 – 3,000,000	3,000,001 – 3,500,000	3,500,001 – 4,000,000

vacuum systems are typically sized based on:

- Design exhaust steam flow
- Total number of exhaust openings

causes: excessive saturated O_2

deaerator Types

None

- > 50 ppb is the expected DO content in condensate without deaeration
- Makeup water can be routed to the top of the ACC for stripping in the overall system

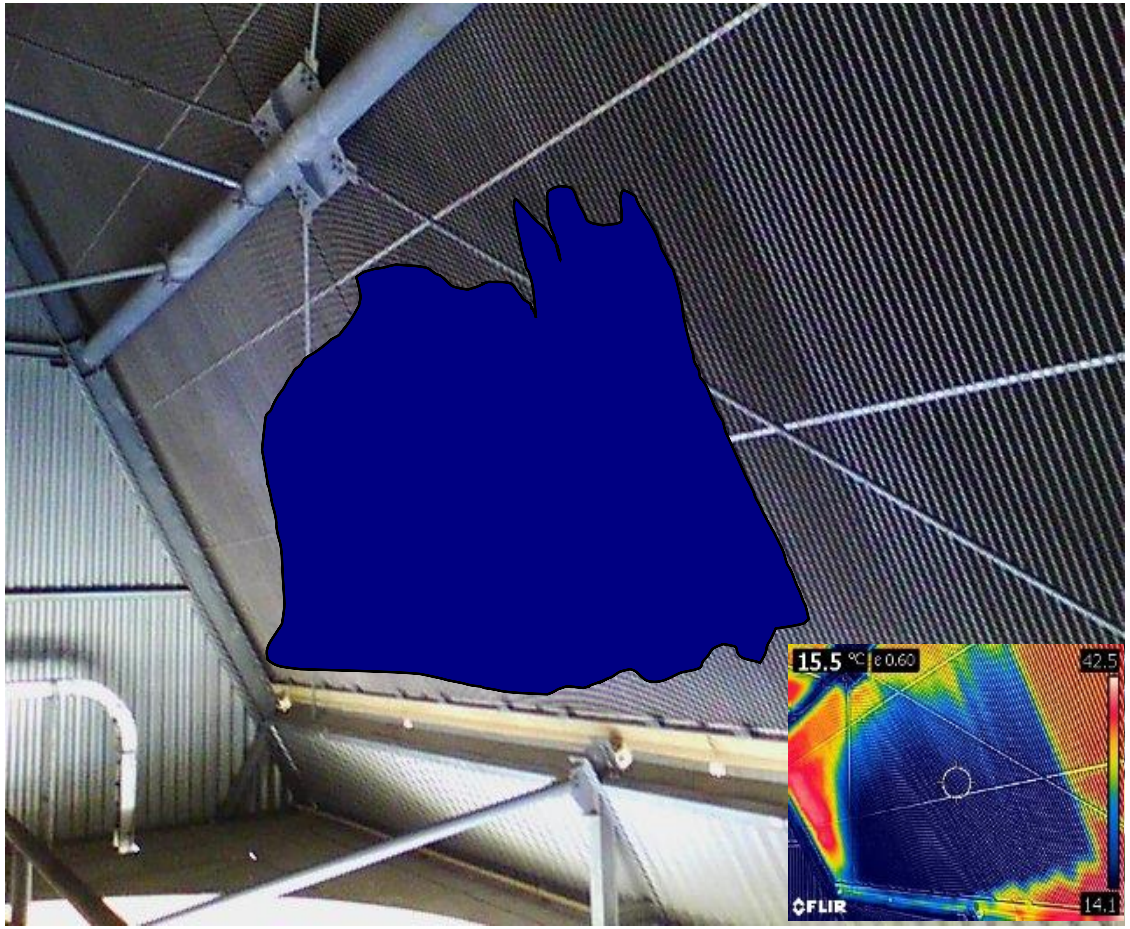
Packing Type

- Dome on top of condensate tank with media to break up condensate flowing into tank
- 7 ppb O2 content can be achieved at normal flows
- 20-50 ppb O2 can be achieved during flows less than 75% of normal

Tray Type

- Can be engineered to achieve 7 ppb O2 or less at all operating flows

causes: excessive air ingress



internal:

holes In tubes or duct

leaking flanges

↓

excessive air ingress

↑

external:

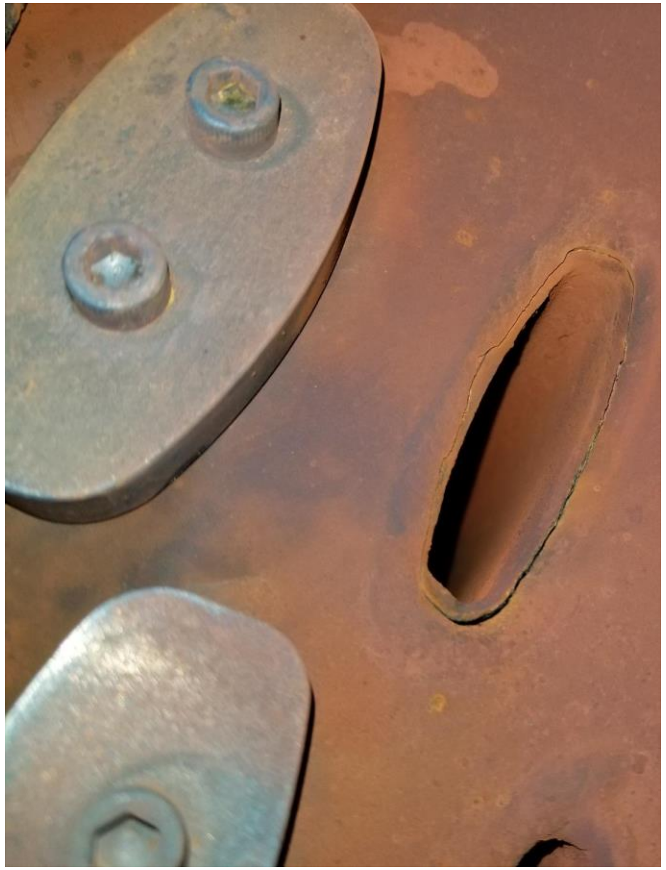
leaking or open valves

rotating equipment seals

causes: internal - excessive air ingress

holes in ACC:

- leaking flanges
- weld seams (likely field welds)
- tubes



causes: external - excessive air ingress

leaks seen near valves & turbine shaft seals

Vacuum Pump Inlet Isolation Valve

Turbine Shaft Seals

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effects

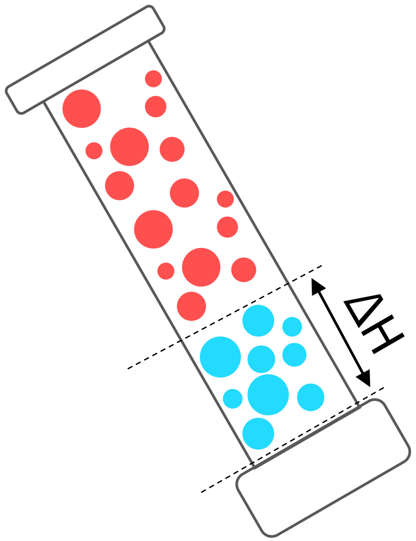
- performance reduction
- freezing risk

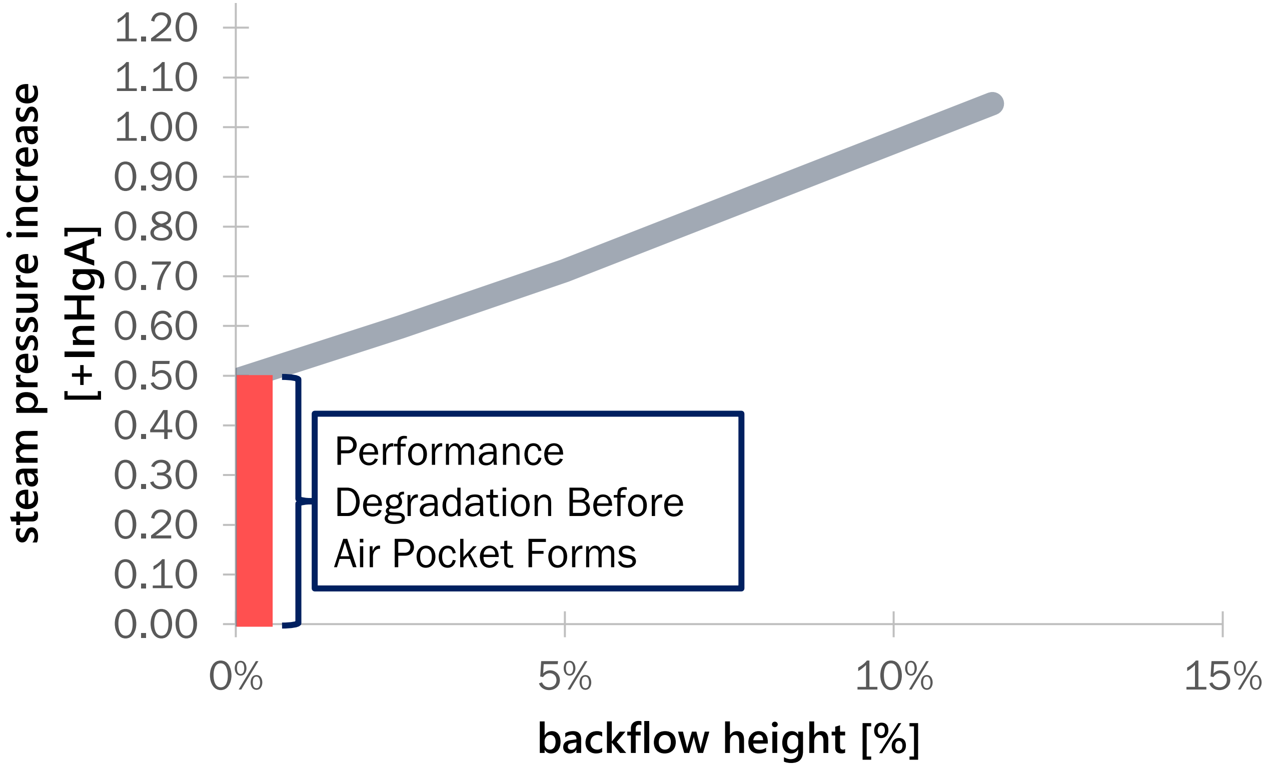
effects: performance reduction

reduction in ACC capability / heat transfer surface area

Tubes filled with air are removed from service

- Total effective tube length decreases
- ACC steam pressure rises

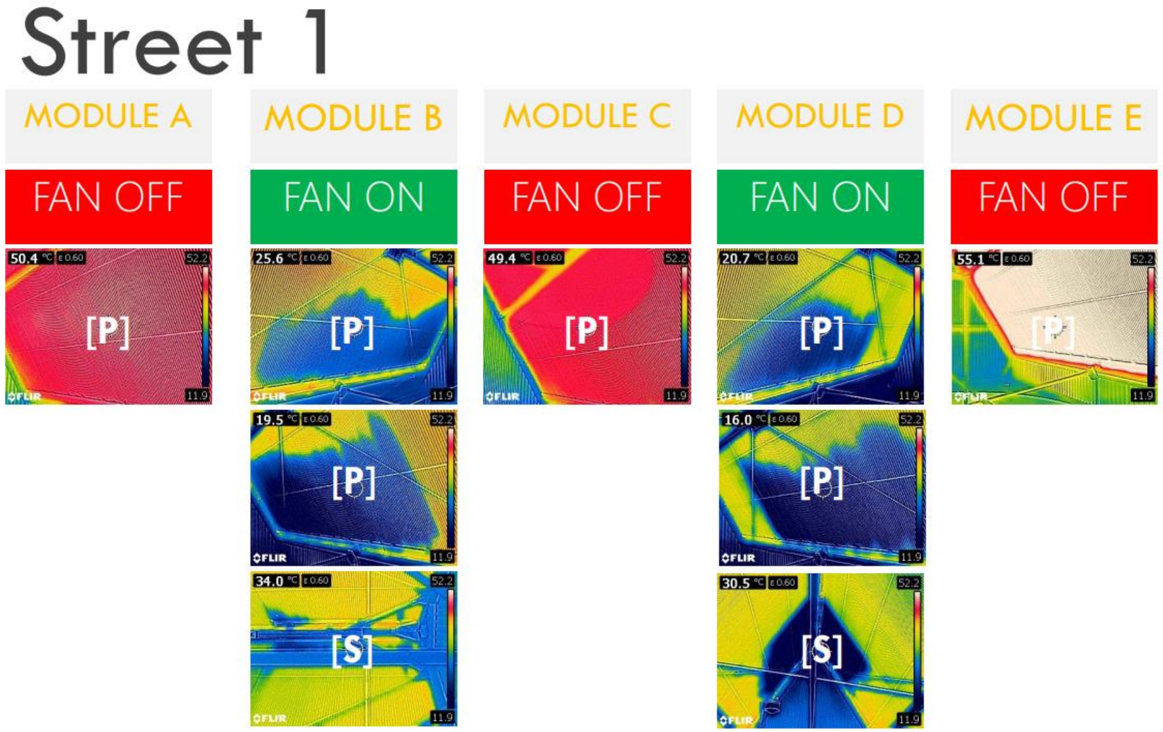




effects: performance reduction

case study: operating A-Frame ACC

- ACC with excessive air ingress due to open valve
- Thermal imaging done in every cell
- Air pocket size estimated in each cell based on field measurements



effects: performance reduction

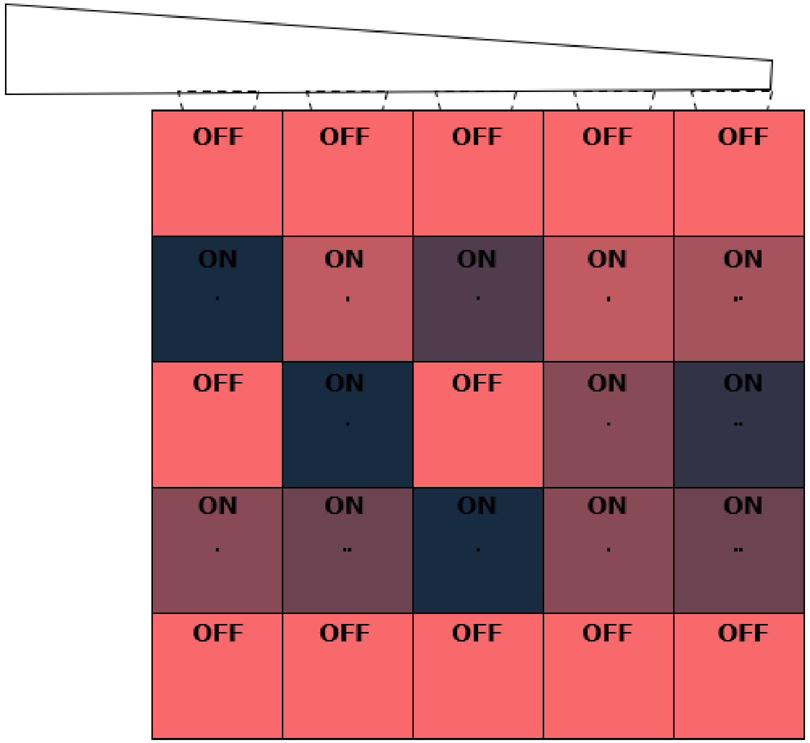
case study: operating A-Frame ACC

12 Fans OFF

- No air pockets witnessed in cells with fans off

13 Fans ON

- Air pockets found in all cells with fans ON
- Backflow

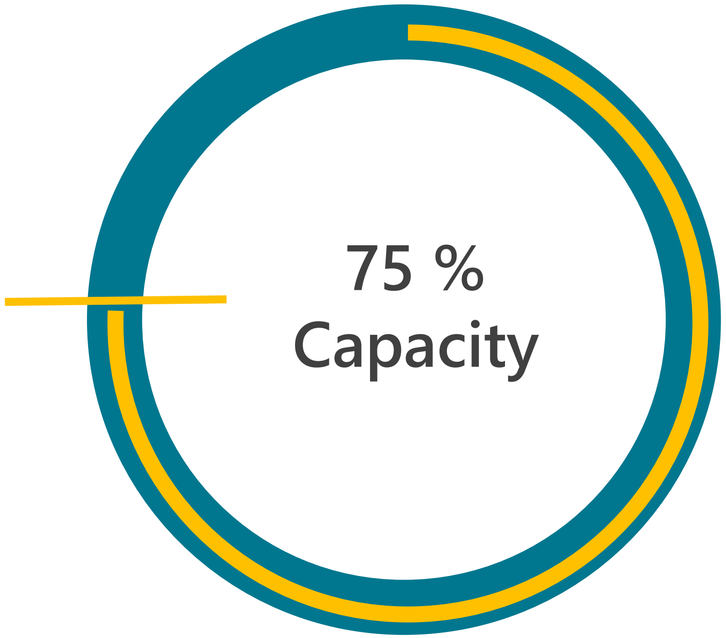


Heat Map of air pocket size

effects: performance reduction

case study: operating A-Frame ACC

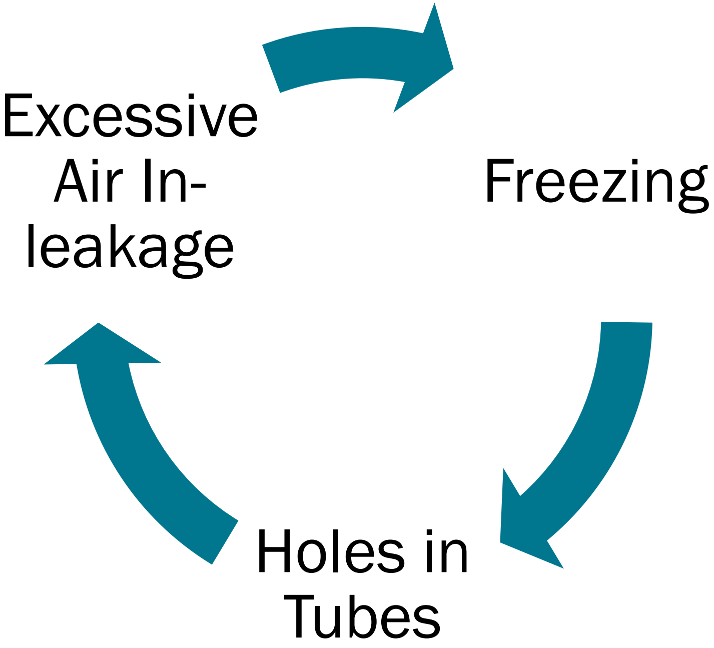
Predicted Conditions				
Item	Unit	Value	Shortfall	Notes
Steam Flow to ACC	[klb/hr]	1,070.45	25%	At measured back pressure
Steam Quality	[%]	0.92	-	
Turbine Back Pressure	[InHgA]	2.38	0.72	At measured steam flow
Inlet Dry Bulb	[°F]	79.41	-	
Inlet Wet Bulb	[°F]	70.41	-	
Fans Operating	[#]	40.00	-	
Duration of Window	[min]	98	-	



Estimated ~25% reduction in ACC capacity due to air pockets

effects: freezing risk

case study: ACC tubes freezing



freezing occurs where air pockets exist

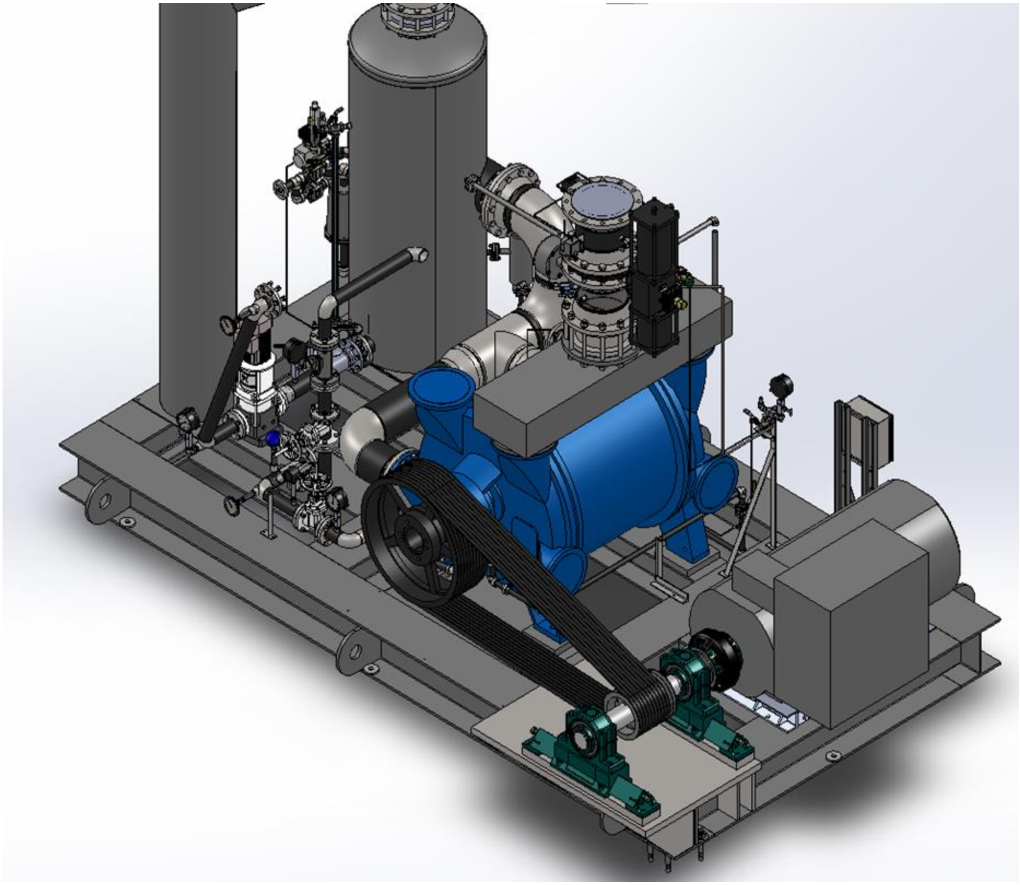
prevention

- auxiliary equipment sizing
- minimize air in-leakage
- ACC design

prevention: properly sized & maintained aux. equipment?

air removal system

- Preventative Maintenance performed?
  - Many flanges ripe for air in leakage…worst place for a leak
- Ensure leak tight system
- Measure airflow for performance evaluation
- Have plant upgrades been made creating more steam load?



prevention: properly sized aux. equipment

deaerator

- Evaluate the original deaerator design
- Determine if upgrading is required
- ASME PTC 12.3 test can be performed

prevention:
minimizing air in-leakage

- Minimize flanged connections
- Minimize field welds
  - Prone to leaks
  - Factory welds can be leak tested in a controlled setting
- Locate and patch leaks
  - Sonic cameras & “gun”
  - Helium tests

evapco® Dry Cooling

prevention: proper ACC design

Even Airflow Distribution + Robust Final Stage of Condensing = Reduced Backflow Susceptibility

prevention: proper ACC design

even airflow distribution

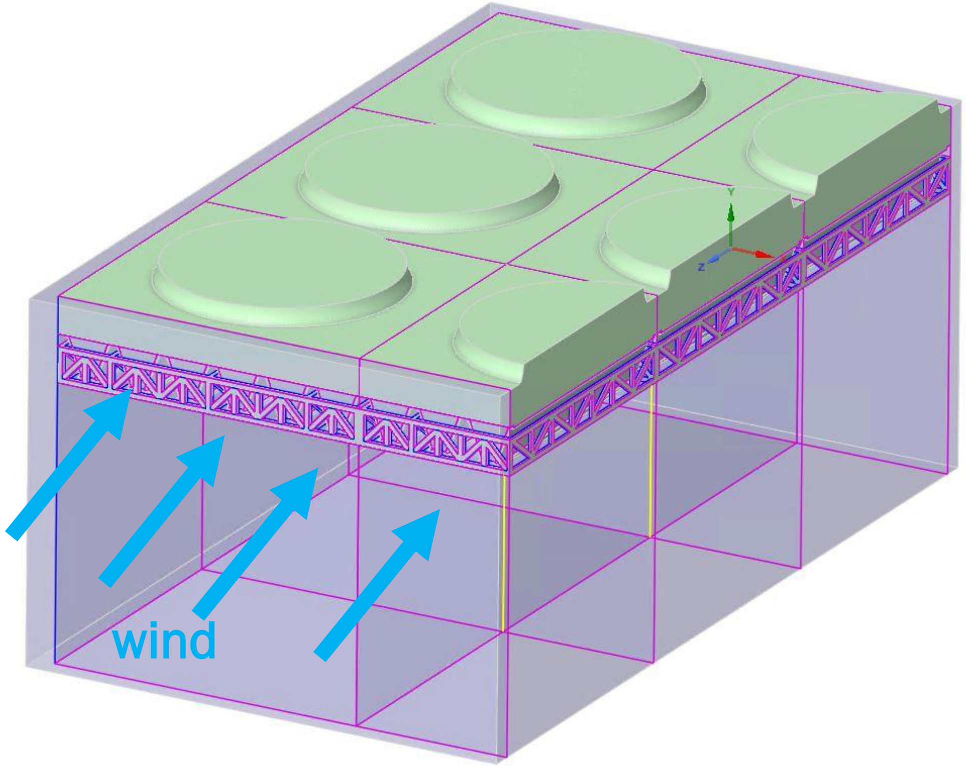
Plenum → Even Air Flow → Normalized Tube Capacity

prevention: proper ACC design

even airflow distribution

Case Study: CFD modeling

- 3D – CFD model to determine air velocity at the bundle face
- design [A] with a plenum vs design [B] with no plenum
- 0 and 5 [m/s] wind



3D Model (design [A] shown)

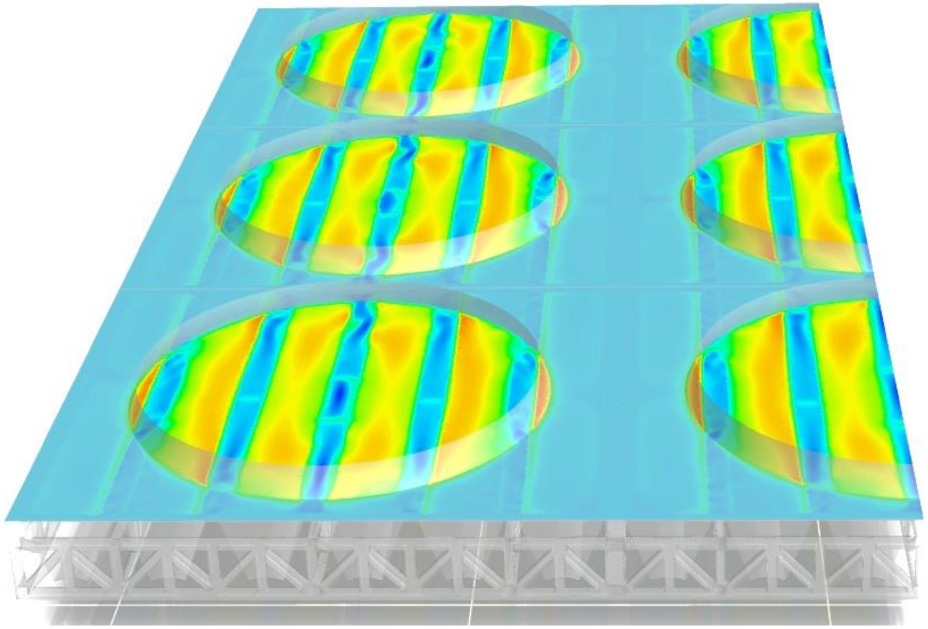
prevention: proper ACC design

even airflow distribution

Plenum → Even Air Flow → Normalized Tube Capacity

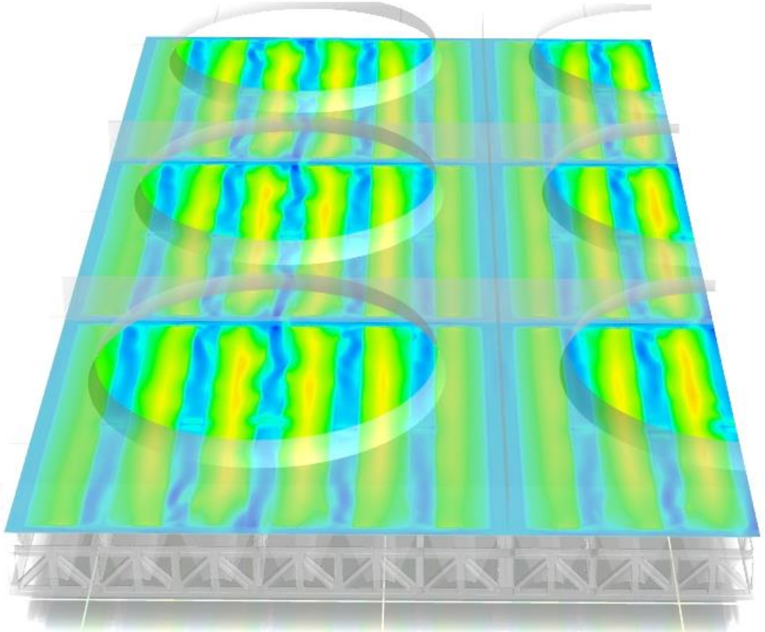
NO PLENUM

- Concentrated high and low velocity air



PLENUM

- Less areas of extreme velocities

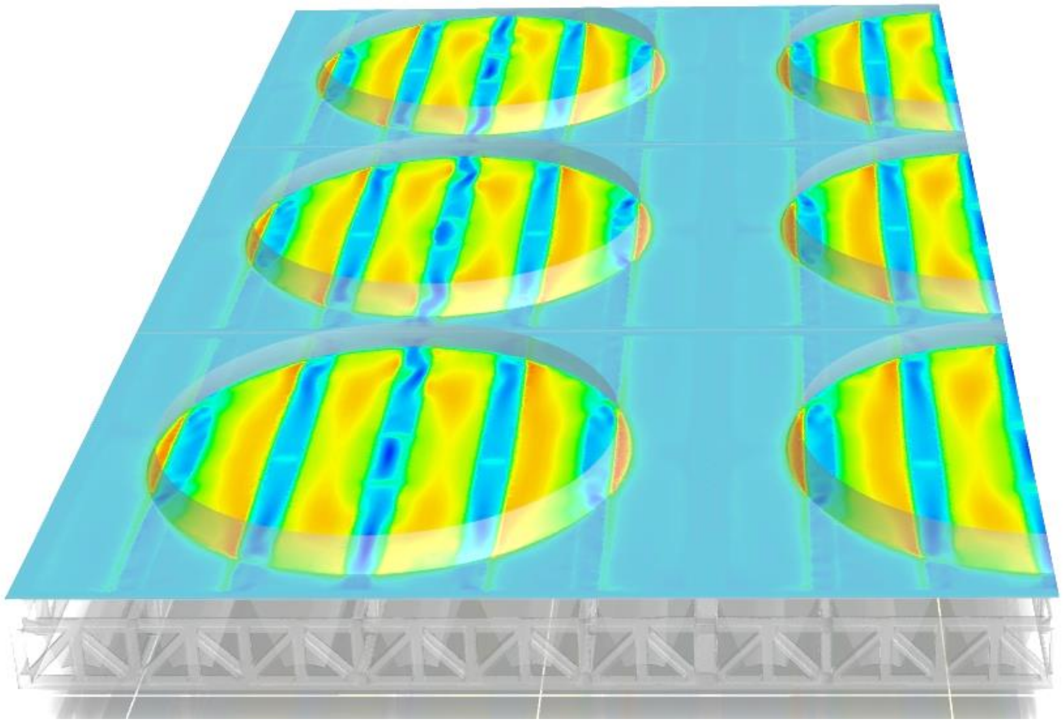


prevention: proper ACC design

even airflow distribution

Plenum → Even Air Flow → Normalized Tube Capacity

Expected loss of ~6% capacity for the no-plenum case due to uneven airflow across the bundles



prevention: proper ACC design

Even Airflow Distribution

+

Robust Final Stage of Condensing

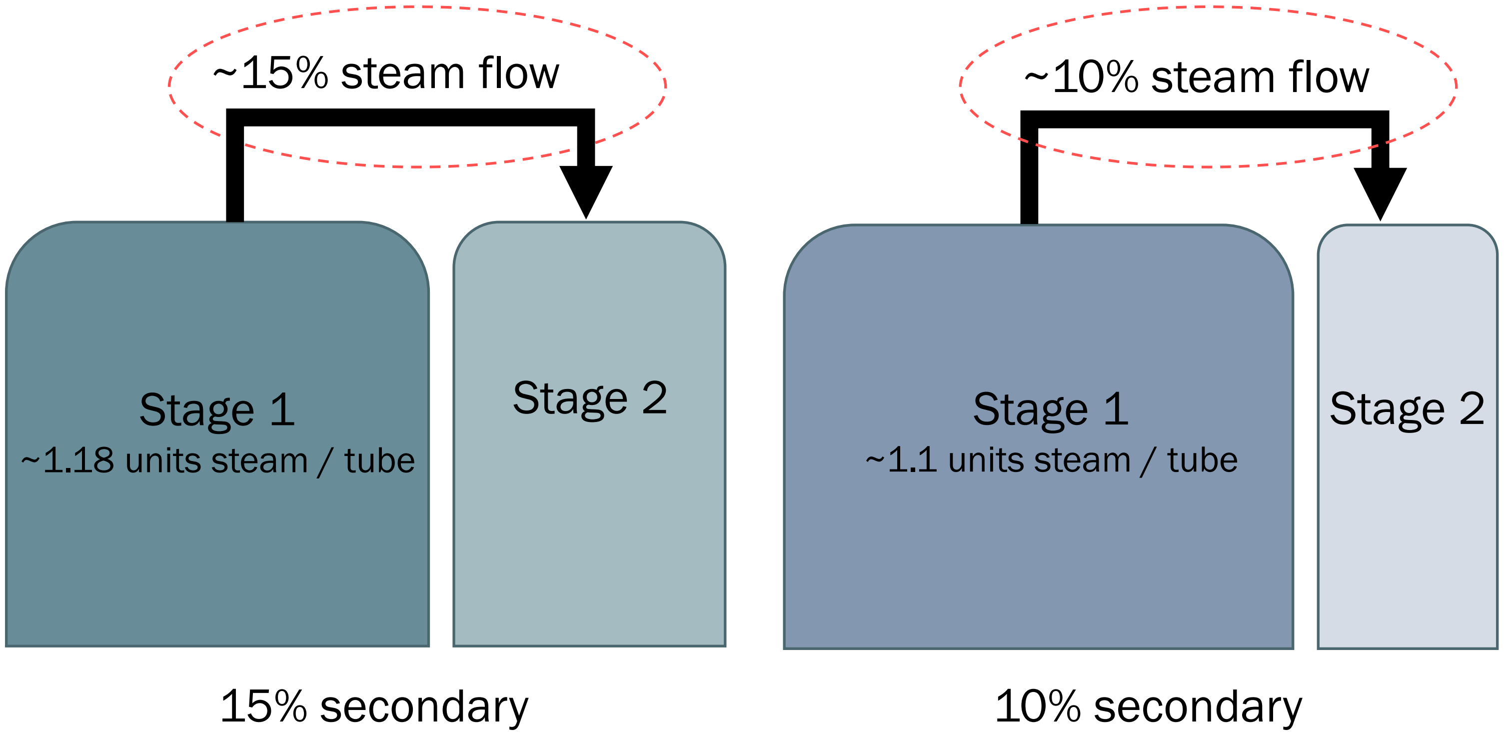
=

Reduced Backflow Susceptibility

prevention: proper ACC design

robust final stage of condensing

- 1st stage tube must condense <u>all</u> of its steam before back flow and air pockets can occur
- Higher % final stage means <u>more</u> steam must be condensed before backflow occurs
- This extra steam is a buffer against back flow!



A-Frame Design Guidelines

- In freezing climates >14%
- In non-freezing climates > 10%

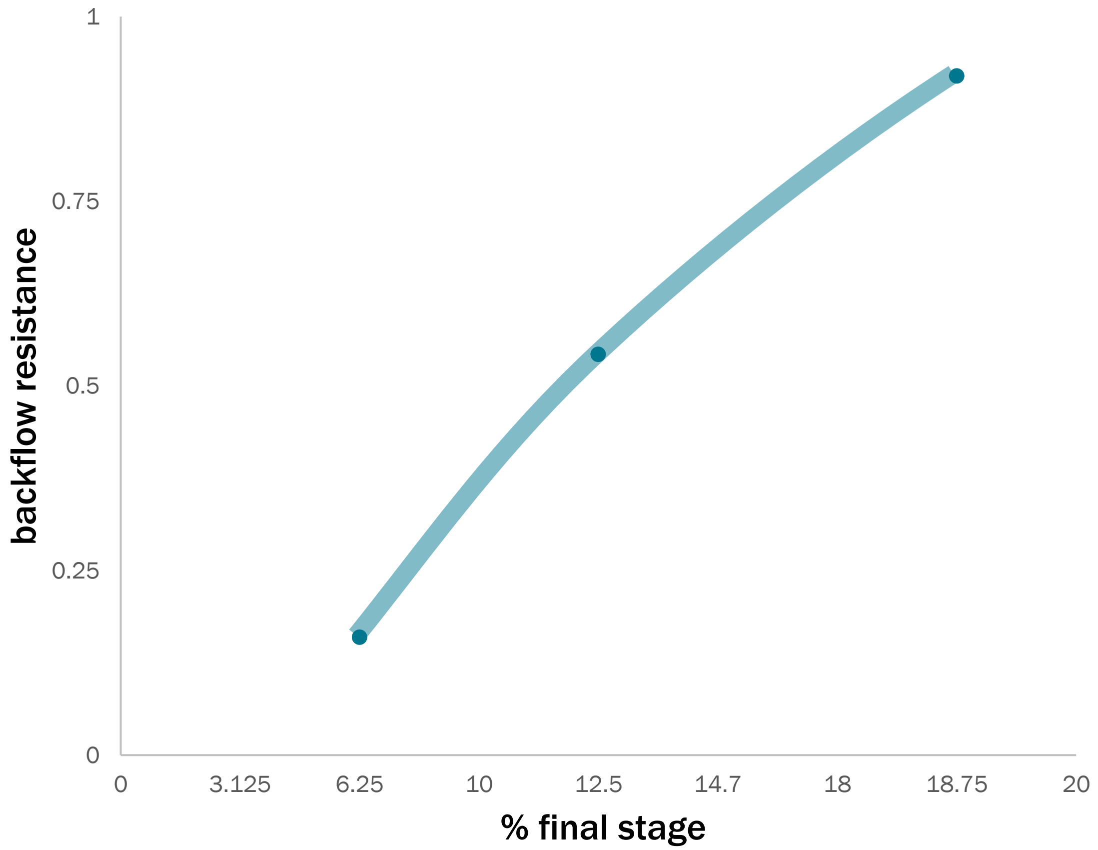
prevention: proper ACC design

robust final stage of condensing

Fluent – CFD Modeling	
Bundle Face Velocity	Airflow Distribution

Arrow - Compressible Flow Modeling	
Evaluate bundle with capacity differences	Predict backflow and develop a resistance

Evapco's rating software	
Build in data to predict backflow	Predict ACC performance



evapco® Dry Cooling

prevention: proper ACC design

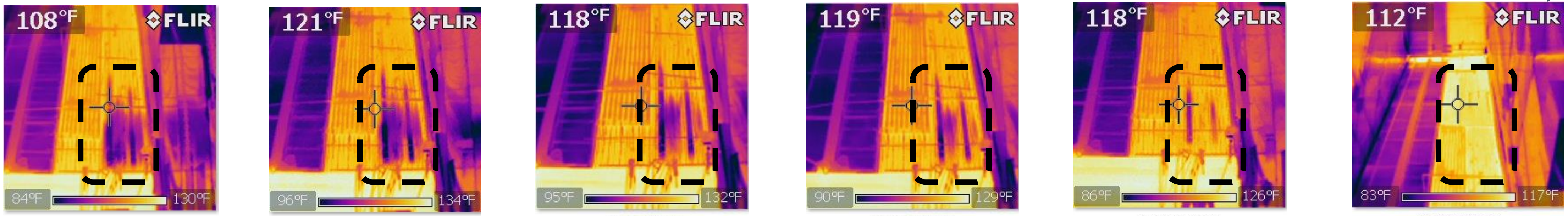
robust final stage of condensing

Case Study in Evapco Steam Lab

- Bundle surface blocked to cause airflow imbalance (creating backflow and air pocket)
- % second stage increased over time to remove air pocket

% second stage | % second stage

<6%	<8%	15% in operation ~30 minutes



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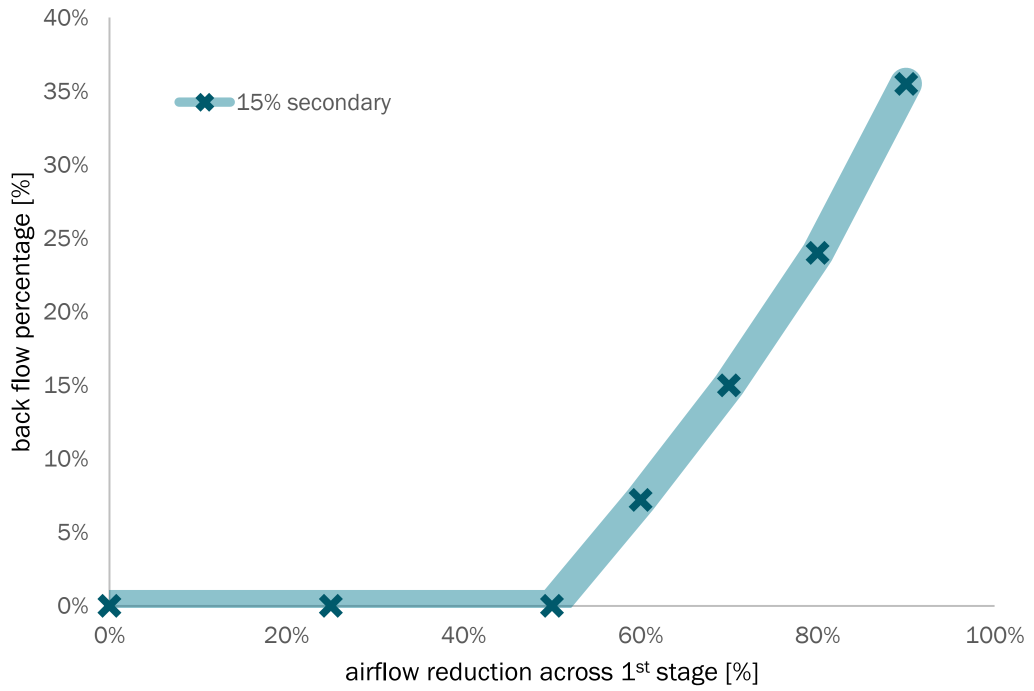
prevention: proper ACC design

robust final stage of condensing

Case Study in Evapco's ACC Rating Software

- Data utilized in in-house rating software
  - Computer model
  - Physical testing
- 50% blockage present before 15% secondaries become insufficient for backflow resilience
- Rating software can predict air pocket presence and size
- Larger second stage results in smaller air pockets



prevention: proper ACC design

key points

- Even airflow distribution for consistent tube capacity
  - ➢ACC less likely to form air pockets
- Robust final condensing stage
  - ➢High resistance to air pocket formation
  - ➢High backflow resistance
- Limiting air in the ACC limits the potential for air pockets
  - ➢Proper design for air removal systems and deaerators can limit available air in the system
  - ➢Monitor and find leaks during operation

summary: air pockets in ACC tubes

- causes
  - Backflow
  - Vacuum System Performance
  - Excessive saturated oxygen
  - Excessive Air Ingress
- effects
  - Performance reduction
  - Freezing risk
- prevention
  - Properly sized auxiliary equipment
  - Minimize air in-leakage
  - Proper ACC design

Questions?

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