Vanderweil Engineers

Ammonia Refrigeration and Risk Mitigation for District Cooling Applications

Presented by: Christopher W. Hastings, PE

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• How suitable is Ammonia for use in District Cooling Applications?
  – Risk
  – First Cost
  – Efficiency
• Feasible Applications
• Ammonia Safety
  – Code required components
  – Regulatory requirements
  – Best practices for leak mitigation
Why Consider Ammonia?

- High Cycle Efficiency
- Continuous use since the 1800’s
  - Mature technology, large equipment manufacturer and contractor base worldwide
- Zero ODP, Zero GWP
- Self-alarming: pungent odor at less than 10 PPM
  - Readily absorbed in water
  - Lighter than air; leaks rise
- Ammonia refrigeration is widely used in urban and suburban locations throughout the U.S.
- Ammonia is being utilized in a number of District Cooling applications in the U.S. and overseas
Application of Ammonia for Large Scale District Cooling

• **Low Temperature Thermal Storage**
  – Dual-temperature NH₃ chillers for ice generation/chilled water production

• **Evaporative Condensers**
  – High cycle efficiency/low first cost
  – Increased NH₃ charge

• **Air-Cooled Condensers**
  – High cycle efficiency/low first cost
  – No water use
  – Increased NH₃ charge

• **Water Chilling/Cooling Towers**
  – Low charge NH₃ PHE screw chillers with ammonia mitigation
Ammonia Chillers

- Custom Fabricated Chillers
- Heat Exchanger Skid
  - Plate Frame Evaporator
    - Flooded – 1.5 lb/TR
    - Direct Expansion DX – under 1 lb/TR
  - Plate Frame Condenser
- Compressor Skid
  - Screw Compressors
    - 2,000 TR
    - Horizontal or Vertical Separators
- Multiple Vendors
Low Temp Thermal Storage Applications

- Screw compressors capable of operating at multiple suction levels +15 deg F, +35 deg F
- Dual evaporator chiller: glycol (ice)/chilled water
- Single compressor serves two (2) chiller evaporators
- Positive displacement; stable operation
- Refrigerant economizer cycle increases efficiency
- Variable VI compressors
- Energy and first cost competitive with Freon centrifugal or screw units
Heat Rejection Options

**Example:** 10,000 TR Cooling Tower System vs. Evaporative Condensers

**Cooling Towers:**
- 20,000 gpm, 85°-100°, 65°wb
  - (5) Tower Cells: 75 HP, 375 HP
  - (5) Pumps: 150 HP, 750 HP
  - Total System KW/TR: 0.85 KW/TR
  - 30” Mains
  - 12” Connections at chiller
Cooling Tower

Step 1

Condenser Heat Transfer

Refrigerant ➔ Vapor ➔ Refrigerant ➔ Liquid

Step 2

Cooling Tower Approach

Tower ➔ Water Pump ➔ Heat Rejection

Air In ➔ Air Out

Lockout tower fans before bypass

Control Valve

Balance Valve

Condenser
Evaporative condenser achieves lower approach between refrigerant and ambient heat sink.
Condenser Water System Options

• 2,000 TR Evaporative Condenser:
  – (2) cells per unit,
    Fans 150 HP,
    Pumps 15 HP
  – Total system: 0.73 KW/TR

• Piping:
  – 8” RD line (vapor)
  – 3” HPL line (liquid)
  – Close coupled to chiller
Evaporative Condenser

**Pros:**

- Improved Efficiency:
  - Saves 15% Plant Power (1,400 HP)

- Piping Savings:
  - Condenser water system eliminated
  - Significant cost savings

**Cons:**

- Increased NH$_3$ charge
- Water treatment at individual basins
Air Cooling

- High cycle efficiency when using direct air cooled condensers
- Middle East application: CHW production 0.95 kW/TR at 40 deg C design
- Lower first cost than many competing technologies
Thermal Energy Storage System

WORLD’S LARGEST THERMAL ENERGY STORAGE SYSTEM

Riyadh Power Plant 9 – PP9 –, in the Kingdom of Saudi Arabia houses the largest Thermal Energy Storage (TES) system in the world.

The plant owned by Saudi Electricity Company and is based on state-of-the-art technology developed by ARABIAN EMCO and ARANER. The 4x(4) gas turbines and respective auxiliaries such as Lube Oil Generator and electrical Components can be started at the same time, raising the overall power output to maximum of 912 MW. This extra power output is equivalent to the total power supplied by a typical power plant. TES system allows a great flexibility in operation and means the electricity supply during power emergency periods.

The TES system (Thermal Energy Storage for Turbine Inlet Air Cooling) increases the total power output of the plant when required. The efficiency and power output of the gas turbines would considerably as the temperature of the turbine inlet air rises (see chart: the U.S. turbines indicated) in PP9 where Emco was the UPCR Contractor.

PP9 TESTIAC SCHEMATIC DIAGRAM

Main TESTIAC Plant Parameters:
- Ambient Temperature: 39°C
- Gas Turbine Model: GE MS7001EA
- Number of Thermal Energy Storage Blocks: 4
- Number of Chillers: 30
- Total Cooling Load: 128,000 Ton (refrigeration)
- Total Refrigeration Capacity stored: 710,000 Ton (refrigeration)
- Electric Power Generation – EXTRA CAPACITY
  - Design conditions cooling (operating on Gas or Crude): 912 MW
  - Emergency conditions cooling: 12 MW

POWER PLANT KEY
1. Turbine Oil Coolers
2. Filter House
3. Inlet Air Coolers (IAG)
4. HD Cooling Chilled Water Pumping Group
5. Generator
6. Transformer
7. Water tank
8. Water Distribution Pipe
9. Turbine Energy Storage Tank
10. Heat Rejection Devices
11. Machinery Room
Ammonia Detection

- Ammonia is a toxic, *Highly Hazardous*, regulated chemical
- OSHA requirements for PSM: OSHA 29CFR 1910.119
- EPA requirements for RMP for systems with over 10,000 lbs: EPA 40CFR, Part 68
- Additional regional regulations: CaLARP, NJTCPA

<table>
<thead>
<tr>
<th>Ammonia Concentration in Air (ppm)</th>
<th>Health Symptoms</th>
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<tbody>
<tr>
<td>25 &lt;</td>
<td>Detectable by smell.</td>
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<tr>
<td>30</td>
<td>Uncomfortable; breathing support required.</td>
</tr>
<tr>
<td>50</td>
<td>OSHA PEL exposure limit.</td>
</tr>
<tr>
<td>100</td>
<td>Irritated eyes, throat, and mucous membranes. Mild eye, nose, and throat irritation; may develop tolerance in 1-2 weeks with no adverse effects.</td>
</tr>
<tr>
<td>140</td>
<td>Moderate eye irritation; no long-term effect in exposures of less than 2 hours.</td>
</tr>
<tr>
<td>300</td>
<td>Immediate danger to life limit (IDLH) .</td>
</tr>
<tr>
<td>400</td>
<td>Moderate throat irritation. Damage of mucous membranes with more than one hour exposure.</td>
</tr>
<tr>
<td>1,700</td>
<td>Fatal after short exposures - less than half an hour.</td>
</tr>
<tr>
<td>5,000</td>
<td>Immediate hazard to life.</td>
</tr>
<tr>
<td>15,000 &gt;</td>
<td>Full body protection required.</td>
</tr>
<tr>
<td>160,000</td>
<td>Flammable in air (LEL).</td>
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Typical Practices

• Safety systems required to meet unified national codes and local code requirements which vary regionally
  – Mechanical room construction
  – Ventilation
  – NH$_3$ detection with audible and visual alarms
  – Emergency shutdown stations
  – Diffusion systems, fireman control station, siamese dump connection
  – Code compliant construction largely not intended to mitigate releases
Worst Case Leak Scenario

• **Example:** Loss of system containing 3,500 lbs ammonia charge in 10 minutes
• Average ammonia vaporization rate of approximately 144 lb/min
• Expected maximum room concentration of 130,000 PPM
• How do you mitigate operation of exhaust system discharging large quantity of ammonia?
• Suggested mitigation criteria: Discharge exhaust concentration mitigated to below OSHA PEL (Permissible Exposure Limit)
Worst Case NH$_3$ Release with 40% Flashed (144 lb/min)
10,000 Ton Equipment Arrangement
New Ammonia Chiller Plant

- **New Ammonia Chiller Plant:**
  - 10,000 TR
  - Five (5) 2,000 TR chiller modules
    - Low refrigerant charge technology
  - **Ammonia Containment**
    - Chiller cells provide primary containment boundary
    - Once-through scrubber system
    - Primary ammonia containment and ammonia transfer areas controlled to negative pressure
    - Secondary containment area: remainder of plant room
Typical Chiller Cell

- Contains 2,000-ton chiller and ammonia leak collection sump
- Tight masonry construction
- Explosion blowout panels sized for max room pressure
- Chiller E-stop inside and outside each cell
- Scrubber: Removal of ammonia during leak event
- HVAC: Provides negative pressurization and space conditioning
- Diffusion Tank: Captures ammonia during PSV releases
- NH$_3$ Sensors: 0 - 20,000 ppm, multiple sensors
- Electrical Room Classification: Class I, Div 2
- Shunt-trip Unclassified Electrical Equipment: 20,000 PPM
Ammonia Scrubber System

- Ammonia scrubber system sized for 100% redundancy
- Packed tower type scrubber; FRP construction
- 22,000 CFM once-through air per chiller cell
- 22,000 CFM once-through air per scrubber (50 PPM outlet)
- Emergency back-up power supply
- Specialty bubble tight isolation dampers on each cells scrubber exhaust duct
- Explosion-proof motors and electrical devices
HVAC System

- Primary/secondary containment areas with active room pressure and flow control
- Headered make-up and exhaust air systems
- 100% fresh air supply to primary ammonia transfer control areas
- Specialty bubble tight isolation dampers at primary containment cells
- 22,000 CFM per chiller cell (air cooled motors)
- 5,700 CFM per chiller cell (TEWAC motors)
Conclusions

• Ammonia is not a mainstream technology for District Cooling
• Ammonia is efficient and cost competitive in applications that favor available technology
• Ammonia refrigeration is reliable and safe
• Mitigation systems can be employed to reduce risk
• Additional information on Natural Refrigerants can be found at:
  – www.iiar.org  International Institute of Ammonia Refrigeration
  – www.reta.com  Refrigerating Engineers & Technicians Association
  – www.eurammon.com  Eurammon Initiative for Natural Refrigerants
  – www.iifiir.org  International Institute of Refrigeration
Heat Recovery Technologies

- **Heat Pump Scavenging System**
  - \( \text{NH}_3 \) heat pump compressor connect to 2,000 TR chiller

- **Potential Technologies**
  - Scavenging compressor utilizing refrigerant discharge gas
  - Heat recovery chiller utilizing cooling tower water

- **Multiple Vendors Offer “Standard” Products**
  - Vilter
  - Frick/Sabroe

- **COP of ~6.0**
Heat Recovery

- Recover heat from process cooling to offset fossil fuels at distributed boilers
- Requires simultaneous heating and refrigeration loads
- Waste heat low grade 90 deg F with straight refrigeration cycle
- Increase quality of available heat with further compression and temperature increase to 120 - 140 deg F
- Scavenging heat pump NH₃
- Transcritical CO₂
- Evaluate additional power requirements for compression and fossil fuel burned