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Air Cooled Absorption for Power Applications

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Module 1: Introduction/Background

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary market barriers to implementing absorption chillers in light-commercial CHP systems.
- **Evaluate** the technical hurdles associated with air-cooled lithium bromide (LiBr) systems compared to water-cooled alternatives.
- **Select** appropriate mitigation strategies (mechanical or chemical) to address crystallization in absorber units.

Executive Summary: The transition of Combined Heat and Power (CHP) systems to the light-commercial market is currently hindered by the operational and economic burdens of cooling towers. Developing air-cooled LiBr-water absorption technology is critical to eliminating these barriers, though designers must overcome significant crystallization limits inherent in air-rejection cycles.

CHP Systems in Light-Commercial Markets

Combined Heat and Power (CHP) systems are a staple in U.S. industrial and institutional sectors but remain underutilized in commercial buildings. The DOE Distributed Energy Program is currently bridging this gap by promoting technologies that utilize waste heat for space cooling via absorption chillers.

Barriers to Absorption Cooling

The standard requirement for a **cooling tower** to reject heat from the condenser and absorber is the primary obstacle in the 10 to 150 RT light-commercial range. Cooling towers are often rejected by building owners due to several factors:

- **Biological Risks:** They can serve as breeding grounds for **Legionella** bacteria.
- **Financial Impact:** They significantly increase initial **capital costs**.
- **Operational Overhead:** They require intensive, regular **maintenance**.
- **Spatial Constraints:** They demand substantial physical **footprint** on-site.

Technical Hurdles and Solution Paths

Transitioning to air-cooled technology eliminates the cooling tower but introduces a "thermal compressor" challenge. Unlike water-cooled systems, air-cooled units must operate under conditions that push the working fluid toward its **crystallization limit**.

⚠ **Safety Constraint:** Crystallization in the absorber is the primary technical failure mode for air-cooled LiBr systems. If the solution solidifies, the chiller will cease operation and may require intensive thermal or mechanical intervention to restart.

Engineers typically address this limit through two primary avenues:

1. **Mechanical Innovation:** Utilizing improved heat exchanger designs to enhance heat and mass transfer.
2. **Chemical Modification:** Employing additives, such as the **Carrol** solution, to shift the crystallization curve and allow for higher temperature ranges in single-effect machines.

Scope of Investigation

This module focuses specifically on **LiBr-water absorption** and the mechanical/chemical aspects of air-cooling. While other technologies exist, they are classified as outside the primary scope of this technical review:

- **Ammonia-water** absorption.
- **Adsorption** or chemisorption systems.
- **Waste-heat-fired Rankine cycles** driving vapor-compression equipment.
- **Ground-coupled** heat rejection.

💡 **Design Tip:** While Asian manufacturers have successfully commercialized air-cooled products for moderate climates using mechanical approaches, these designs are often insufficient for the extreme temperature swings found in U.S. climate conditions.

Checkpoint Quiz

1. **Which of the following is the most significant technical hurdle when designing an air-cooled LiBr absorption system?**
   a) High parasitic power for solution pumps
   b) Crystallization limit in the absorber
   c) Lack of waste-heat streams in commercial buildings
   d) Incompatibility with solar-fired generators

Answer: (b). Crystallization is the main technical barrier noted in past development work.

2. **Why is the "Carrol" solution significant for single-effect absorption machines?**
   a) It eliminates the need for a solution heat exchanger.
   b) It allows the system to use ammonia instead of LiBr.
   c) It is a chemical additive that helps the system handle wider temperature ranges by shifting the crystallization curve.
   d) It reduces the physical footprint of the condenser to zero.

Answer: (c). Carrol is a specific chemical approach used to inhibit crystallization at relevant temperatures

3. A developer is considering a cooling tower for a 50 RT CHP system in a small office complex. Which factor is most likely to discourage the owner according to DOE findings?

a) The lack of qualified operators for Rankine cycles.
b) High maintenance requirements and risk of Legionella.
c) The requirement for high-grade industrial waste heat.
d) The inability to use lithium bromide as a sorbent.

Answer: (b). Maintenance, cost, space, and biological risks are the primary barriers to cooling tower adoption in light-commercial settings.

Module 2: LiBr Absorption Overview

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the core components of the "thermal compressor" assembly and their functions within the cycle.
- **Evaluate** the phase changes and pressure dynamics of water as the refrigerant in a LiBr-water system.
- **Select** between secondary-loop dry cooling and direct air-cooled absorber/condenser configurations for CHP applications.

Executive Summary: The LiBr-water absorption cycle replaces the mechanical compressor of a vapor-compression system with a thermal compressor assembly—consisting of an absorber, pump, heat exchanger, and generator—that operates entirely below atmospheric pressure. In CHP applications, this cycle leverages waste heat to drive the refrigeration process, requiring specific modifications to the absorber and condenser for air-cooled heat rejection.

The Thermal Compressor Assembly

The absorber, pump, solution heat exchanger, and generator assembly essentially replaces the mechanical compressor found in traditional vapor-compression refrigeration systems. This assembly is frequently termed a **thermal compressor**. The cycle operates as follows:

- **Dilute Solution Transport:** A weak solution (dilute LiBr in water) is pumped from the absorber toward the generator.
- **Solution Preheating:** A solution heat exchanger preheats the weak solution before it enters the generator.
- **Refrigerant Separation:** Heat is added to the generator to boil off the water vapor (the refrigerant) from the solution.

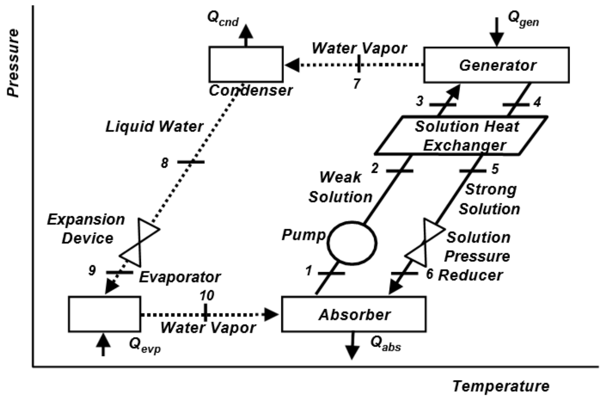

Figure 1: Basic Single-Effect LiBr Absorption Cycle

Refrigerant and Solution Flow

Once the refrigerant is separated, it follows a distinct path to provide cooling, while the concentrated sorbent returns to repeat the absorption process:

- **Condensation:** Water vapor flows to the condenser, where it condenses and rejects heat to the ambient environment.
- **Expansion and Evaporation:** Condensed water passes through an expansion device to reduce pressure, then enters the evaporator. Here, heat from the load evaporates the water, providing the desired cooling effect before the vapor returns to the absorber.
- **Solution Concentration:** When water is boiled out in the generator, the remaining solution becomes **strong** (high LiBr concentration).
- **Pressure Reduction:** The strong solution is cooled in the solution heat exchanger and passes through a flow restriction to lower its pressure before returning to the absorber.

Absorption and Heat Rejection

The cycle is completed when the strong solution in the absorber absorbs the water vapor returning from the evaporator, which dilutes the solution.

- **Heat of Vaporization:** Because the water vapor returns to a liquid state during absorption, the process releases the heat of vaporization, which must be rejected from the system.
- **Operating Pressure:** It is critical to note that the entire cycle operates **below atmospheric pressure**.

CHP and Air-Cooling Configurations

In CHP applications, waste heat from the prime mover—rather than fossil fuel combustion—supplies the energy to the generator. To eliminate the traditional cooling tower in these systems, engineers have two primary air-cooling options:

1. **Secondary Loop with Dry Coil:** Utilize conventional water-cooled components but substitute a **dry coil** for the cooling tower to reject heat to the ambient air.
2. **Direct Air Cooling:** Replace the condenser and absorber units with dedicated **air-cooled** versions.

💡 **Design Tip:** While using a secondary loop and dry coil allows for standard chiller components, direct air-cooled absorbers and condensers eliminate the intermediate heat transfer step, potentially improving system performance if crystallization limits are managed.