Sustainable Energy

Mod. 1: Fuel Cells & Distributed Generation Systems

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Lesson XXII: Trigeneration
General Aspects (1/3)

- Trigeneration: production of three useful energy forms (electrical, hot thermal and cold thermal) with only one plant (only one fuel)
- CCHP plants: Combined Cooling Heating and Power plants
- For cold energy generation (from hot energy) an absorption chiller is necessary
- Trigeneration is essential for using thermal energy in summer too (cooling power is mainly used for building conditioning)
- Absorption chillers use hot thermal energy to produce cold thermal energy (a minimum amount of electricity is necessary for pumps)
General Aspects (2/3)

✓ Trigeneration approach
General Aspects (3/3)

✓ General seasonal load demand

![Graph showing load demand, heating demand, cooling demand, and electrical demand over a year.]

- Load demand (referred to heating peak)
- Month number
- Heating demand
- Cooling demand
- Electrical demand
Conventional Chillers (1/2)

✓ Vapour compression chillers

Coefficient of performance (COP): \( \text{COP} = \frac{Q_{\text{in}}}{W_c} \)

Working fluid: refrigeration fluid (e.g. R134a: \( \text{C}_2\text{H}_2\text{F}_4 \))
Conventional Chillers (2/2)

✓ Ideal Carnot reverse cycle for vapour compression chillers

\[
\text{COP}_C = \frac{Q_{in}}{W_c} = \frac{Q_{in}}{|Q_{out}| - Q_{in}} = \frac{1}{|Q_{out}/Q_{in} - 1|} = \frac{1}{((R \cdot T_H \cdot \ln(v_3/v_4))/(R \cdot T_L \cdot \ln(v_2/v_1)) - 1)} = \frac{1}{(T_H/T_L - 1)} = T_L/(T_H - T_L)
\]

If \( T_H = 30^\circ\text{C} \) and \( T_L = 7^\circ\text{C} \): \( \text{COP}_C = 13.2 \)

For the real cycle, \( \text{COP} \approx 5.0 \) (compressor efficiency = 0.7)

Usually \( T_1 = T_L - (5-10^\circ\text{C}) \) and \( T_4 = T_H + (5-10^\circ\text{C}) \)

If the useful effect is heating (instead of cooling) the device is called heating pump
Absorption Chillers (1/4)

- Working fluids: refrigerant, absorber
- Fluid examples:
  - $\text{H}_2\text{O}$ (refrigerant) and LiBr (absorber) for cold temperatures of 5-7°C
  - $\text{NH}_3$ (refrigerant) and $\text{H}_2\text{O}$ (absorber) for cold temperatures of -20°C

\[ \text{COP} = \frac{Q_{\text{in}}}{Q_{\text{out}}} \]
Absorption Chillers (2/4)

If water is refrigerant, vacuum conditions are necessary.

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Absorption Chillers (3/4)

✓ Ideal Carnot reverse cycle for absorption chillers

Carnot direct cycle efficiency between $T_S$ and $T_H$

Carnot inverse cycle COP between $T_L$ and $T_H$

If $T_S = 95^\circ C$, $T_H = 30^\circ C$ and $T_L = 7^\circ C$: $\text{COP}_C = 2.2$

For the real cycle: $\text{COP} \approx 0.75$

From second principle: $Q_{in}/T_L - |Q_{out}|/T_H + Q_S/T_S = 0$

COP$_C = Q_{in}/Q_S = Q_{in}/(|Q_{out}| - Q_{in}) = 1/(|Q_{out}|/Q_{in} - 1)$

Combining the equations: $\text{COP}_C = (T_S - T_H)/T_L * T_L/(T_H - T_L)$
Absorption Chillers (4/4)

Comparison with vapour compression chillers
✓ Absorption chillers have a low COP value (0.15-0.2 times than vapour compression chillers)
✓ Also considering primary energy consumption (considering an electrical plant producing at 40%), vapour compression chillers consume 40% of the fuel requested for absorption chillers
✓ Absorption chillers are more expensive than vapour compression chillers
✓ Moreover, absorption chillers are more complex to be managed

So, why absorption chillers are produced?
✓ Absorption chillers are benefitting when it is necessary to recover waste energy (as at from exhaust of a power plant)
✓ Absorption chillers are an interesting technology where high electrical power lines are not available
✓ Absorption chillers are also interesting for exploiting solar thermal energy in summer (when heating demand is close to zero)
Examples of Trigeneration Systems (1/4)

Trigeneration system installed in the laboratory of TPG

Absorption chiller: 102 kW cold
Chilled water temperatures: 7-12°C
Nominal COP: 0.75
Examples of Trigeneration Systems (2/4)

- Trigeneration system installed at PROPLAST RICERCE
  - Location: Rivalta Scrivia (AL)
  - User: Industry
  - Activation year: 2004
  - Prime mover technology: Microturbine
  - Fuel: Natural gas
  - Electrical power: 120 kW
  - Thermal power: 230 kW
  - Cooling power: 120 kW
Examples of Trigeneration Systems (3/4)

Trigeneration system installed at Dorno AUTOGRILL
- Location: Dorno (PV)
- User: Restaurant building
- Activation year: 2006
- Prime mover technology: Microturbine
- Fuel: Natural gas
- Electrical power: 60 kW
- Thermal power: 115 kW
- Cooling power: 70 kW
Examples of Trigeneration Systems (4/4)

- Trigeneration system installed at M&G
  - Location: Tortona (AL)
  - User: Offices
  - Activation year: 2004
  - Prime mover technology: Microturbine
  - Fuel: Natural gas
  - Electrical power: 30 kW
  - Thermal power: 65 kW
  - Cooling power: 35 kW