Cycle Simulation and Prototyping of Single-Effect Double-Lift Absorption Chiller

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<tr>
<th>Temp.</th>
<th>60°C</th>
<th>90°C</th>
<th>120°C</th>
<th>150°C</th>
<th>180°C~</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(75°C)</td>
</tr>
</tbody>
</table>

- **Hot Water Driven Absorption Chiller**
  - Single effect

- **Steam Driven Absorption Chiller**
  - Double effect

- **Direct fired Absorption Chiller/Heater**
  - Not Available for Cooling Use
2. Single-Effect Double-Lift (SEDL) absorption cycle

SEDL absorption cooling cycle

- Combination of single-effect and double-lift (half-effect) absorption cycle
- Consist of 7 phase changing heat exchanger and 3 solution heat exchanger
- Proposed by Schweigler et. al. in 1990’s
3. Cycle Simulation
Simulation model supported two-step evaporator and absorber (E/A).

Operated under 4 pressure levels

Configuration of two-step E/A

Refrigerant liquid

Refrigerant vapour

Chilled water

Cooling water

Strong solution

Weak solution
3. Cycle Simulation – Computing strategy

Basically, cycle calculation is consist of three levels.

(1) Whole system level
Energy and mass balance in the whole cycle

(2) Same pressure level
Mass balance in each pressure level $p_H$, $p_M$, $p_{L1}$ and $p_{L2}$

(3) Components level
Energy and mass balance in each component in the same pressure level
3. Cycle Simulation – Effect of two-step E/A

As similar as conventional machines, two-step E/A configuration improved the capacity and COP. → We employed two-step E/A for the prototype chiller.

Evaporator and absorber formation

Evaporator and absorber formation (Calculation under the same heat exchanger size)

Capacity (QE), COP

<table>
<thead>
<tr>
<th>Capacity (QE), COP (%)</th>
<th>THW-out</th>
</tr>
</thead>
<tbody>
<tr>
<td>102</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td></td>
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<tr>
<td>98</td>
<td></td>
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<td>97</td>
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<td>96</td>
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<tr>
<td>95</td>
<td></td>
</tr>
<tr>
<td>94</td>
<td></td>
</tr>
</tbody>
</table>

2-step EA 1-step EA 2-step EA 1-step EA

Chilled water: 13-8°C Chilled water: 15-7°C

Hot water temperature (THW-out)

Calculation under the same heat exchanger size

Hot water (Heat source)

Refrigerant liquid

Refrigerant vapour

Chilled water

Solution (Absorbent)

Cooling water
Circulation methods for hot water and cooling water were examined and “HG-LG-AG” for the hot water and “A-AA-C” for the cooling water were selected.

Hot water temperature (THW-out) (°C)

Capacity (QE), COP (%)

Hot water and cooling water flow order

Calculation under the same heat exchanger size
4. Prototyping and Experiment
Prototype of SEDL chiller was designed with adoption of two-step evaporator and absorber, and optimized water circulating method. This prototype can also be operated as a normal double-lift cycle.
Prototype of SEDL chiller and experimental equipment are setup for performance test.
Prototype chiller was manufactured, considering real product.

Prototype of SEDL absorption chiller

- Evaporator
- Condenser
- Absorber
- High temp. generator
- Auxiliary absorber
- Auxiliary generator
- Low temp. generator
- Solution heat exchangers
Basic performance data in DL and SEDL operations were measured.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Operating mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DL</td>
</tr>
<tr>
<td>Cooling capacity</td>
<td>kW</td>
<td>42.0</td>
</tr>
<tr>
<td>Chilled water</td>
<td>°C</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0</td>
</tr>
<tr>
<td>Cooling water</td>
<td>°C</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34.5</td>
</tr>
<tr>
<td>Hot water (Heat source)</td>
<td>°C</td>
<td>60.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>56.3</td>
</tr>
</tbody>
</table>
The simulator was validated by comparing with experimental data.

**Accuracy;**
- THW-out: ±1°C (approx.)
- Capacity: ±5% of max. value

In case of THW-in = 60°C, effect of heat leak increases relatively.

We are using this simulator considering this accuracy as enough level.
5. Conclusions
5. Conclusions – activating low temperature heat –

Current status of driving temperatures of absorption chillers

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<td>Single effect</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

- SEDL Absorption Chiller
- Half effect

- Hot Water Driven Absorption Chiller
- Single effect

- Steam Driven Absorption Chiller
- Double effect
5. Conclusions – Comparisons with SE chillers

SEDL reduces hot water volume into about half amount, thus
1) increases cooling capacity per unit hot water volume \((\text{MJ/m}^3_{\text{HW}})\), and
2) reduces pumping power for hot water \((\text{kW}_{\text{el}}/\text{kW}_{\text{Cool}})\).

- **Cooling Capacity**
  - Chilled water: 12 -> 7°C
  - Cooling water: 27 -> 33°C
  - Hot water inlet: 95°C

- **Pumping power**
  - Flow rates of chilled water and cooling water are common
  - Hot water inlet: 95°C
  - HW pumping head: 20m

\[ \text{Cooling capacity per unit hot water volume (MJ/m}^3_{\text{HW}}) \times 2 \]
\[ \text{Hot water pumping power (kW}_{\text{el}}/\text{kW}_{\text{Cool}}) \times 0.5 \]
5. Conclusions – remarks –

Through the development of SEDL chiller, following results are obtained.

(1) A simulation program to study the effect of cycle configuration was developed.

(2) A prototype SEDL absorption chiller with two-step E/A was also developed. Patterns of circulating water were selected to maximize its cooling capacity.

(3) The prototype performed at 106.1kW (30.2RT) in cooling capacity. Chilled water of 7°C was obtained by using 88.7°C hot water, and its return temperature went down to 53.0°C.

(4) This prototype also could be driven in normal double-lift operation. 60°C hot water was used until 56°C and 7°C chilled water is produced.

(5) The simulation program appeared to have enough function and accuracy to predict the behaviour of SEDL absorption cooling cycle.

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Appendix A – Application image

- Low temperature driven heat pump chillers are expected to be used in district heat, solar system and distributed energy systems.

- Wide temperature drop in hot water (i.e. 95 – 55 = 40 °C) reduces the hot water flow rate and pumping power of the system.
Appendix B – Comparison with forerunner’s work

Our project aims at reduction of hot water outlet temperature, hereby increase the application of hot water driven absorption chillers.

<table>
<thead>
<tr>
<th>Hot water temp. (°C)</th>
<th>Cooling water temp. in/out (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[100, 90, 80, 70, 60]</td>
<td>[50, 60, 70, 80, 90, 100]</td>
</tr>
</tbody>
</table>

Cycle scheme

- **SE**: Single effect
- **DL**: Double lift

For Asia
- Present Product
  - Project Düsseldorf
  - ZAE Bayern, 1998
  - ASHRAE Transactions 104 (1998): 1420

For Europe
- Project Berlin
  - 51°C Outlet
  - 31/36.4
  - 27/33

- **This work**
  - 31/37
  - 27/35

Appendix C – Effect of solution heat exchangers –

Referring simulation results, we selected “HHX×2 and LHX ×2”.

Capacity (QE), COP (%)

THW-in: 95°C, Chilled water in-out: 13-8°C

Solution heat exchanger formation