A study on retrofit methodologies for legacy air-conditioning systems to reduce their impact on global warming and ozone depletion

Prepared for the Public Commenting Meeting of Ph.D program

February 28, 2008

Makoto GOTO
Nagoya University
Acknowledgement

- Satoshi OHUCHIDA
- Tomohiro YAMAUCHI
- Prof. Kenji NAGATA
- Dr. Koji TANIFUJI
- Masahiro FUJITA
- Hedeyuki SUZUKI
- Toshio MIYAMOTO
- Prof. Isao UENO
- Prof. Tatsuya HASEGAWA
Outline of the presentation

Chap.1 Introduction

Chap.2 Operation of Air-conditioning Systems by Proposed Methodologies

Chap.3 Circulation of Immiscible Mineral Lubricant Oil in an Air-conditioning System

Chap.4 Application: Performance of a Hot-water Supply System Utilizing Wasted Heat of an Air-conditioning System

Chap.5 Conclusion
Background

Air-conditioning systems consume large amount energy
They have significant global warming impact

HCFC refrigerant should be replaced

HCFC

- has an effect on depletion of ozone layer
- R22
  - abolished by 2020 (Montreal Protocol)

HFC

- has no effect on depletion of ozone layer
  - R407C
    - has difficulty in handling
  - R410A
    - mixture ratio varies due to leakage
  - R134a
    - single refrigerant
    - relatively small GWP
Objectives of the research

- Improving performance of existing legacy systems for HCFC by the proposed methodologies:
  - Retrofitting an additional condenser
  - Replacing refrigerants
    - HCFC22 → HFC134a
- Can mineral oil circulate in the system?
  - (Mineral oil is immiscible to HFC134a)
- Check the scope of the proposed methodologies

What is retrofit?
- Keep using the system as it is by replacing or installing parts
- Not replacing a whole system
Outline of the presentation

Chap.1 Introduction

Chap.2 Operation of Air-conditioning Systems by Proposed Methodologies

Chap.3 Circulation of Immiscible Mineral Lubricant Oil in an Air-conditioning System

Chap.4 Application: Performance of a Hot-water Supply System Utilizing Wasted Heat of an Air-conditioning System

Chap.5 Conclusion
Objectives

- Test proposed methodologies:
  - Operation with an additional condenser
  - Replacing the refrigerant
    - HCFC22 → HFC134a
- Check validity and system improvement
An additional condenser always functions as a condenser for cooling and heating operations.

Indoor unit and outdoor unit are set separately in insulated rooms.

Both cooling and heating operations were performed to measure:
- temperature of refrigerant and air
- refrigerant pressure
- electric current
Experimental setup (Additional condenser)

The tube was divided into four channels to enhance heat exchange.
Results (Cooling operation, Performance)

Definition of the COP

**COP** = \( Q / W \)

- **Q**: the heat exchange at the indoor unit
- **W**: the electric power consumption

**Q** contains inaccuracy due to difficulty in measuring flow rates

To eliminate inaccuracy of the flow rate, introduce the relative COP as follow:

Relative COP

\[ \text{Relative COP} = \frac{\text{COP}}{\text{COP without an additional condenser using HCFC22}} \]
## COP

<table>
<thead>
<tr>
<th>Condition</th>
<th>Relative consumed electric power [%]</th>
<th>Relative heat exchange at evaporator [%]</th>
<th>Relative COP [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCFC22</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>HCFC22+AC</td>
<td>100</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>HFC134a</td>
<td>69</td>
<td>75</td>
<td>107</td>
</tr>
<tr>
<td>HFC134a+AC</td>
<td>68</td>
<td>79</td>
<td>117</td>
</tr>
</tbody>
</table>

- By installing an additional condenser, COP was improved
- By replacing HCFC22 with HFC134a, COP was also improved
- By combining both effects, COP was further improved

Constant outside environment was realized by courtesy of Fuji Giken Industry Co., Ltd.
By installing an additional condenser (AC),

- Refrigerants are more super-cooled at the outlet of the AC
- Heat exchange both at the condenser and at the evaporator are enhanced
- Work done by the compressor does not change
Long term operation data

<table>
<thead>
<tr>
<th>Place</th>
<th>Installation</th>
<th>Operation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>A company</td>
<td>February 4, 2002</td>
<td>3 years and 9 months</td>
</tr>
<tr>
<td>B company</td>
<td>February 23, 2002</td>
<td>3 years and 9 months</td>
</tr>
<tr>
<td>C factory</td>
<td>July 27, 2002</td>
<td>3 years and 4 months</td>
</tr>
<tr>
<td>D factory</td>
<td>December 27, 2003</td>
<td>1 year and 11 months</td>
</tr>
</tbody>
</table>

Data at November 2005 was provided by courtesy of Wasino Trading Corporation

- Longer than 3 years have the systems been working by replacing HCFC22 with HFC134a
Outline of the presentation

Chap.1 Introduction

Chap.2 Operation of Air-conditioning Systems by Proposed Methodologies

Chap.3 Circulation of Immiscible Mineral Lubricant Oil in an Air-conditioning System

Chap.4 Application: Performance of a Hot-water Supply System Utilizing Wasted Heat of an Air-conditioning System

Chap.5 Conclusion
Objectives

- Confirm circulation of refrigerant and mineral lubricant oil
  - Static compatibility test
  - Flow visualization
  - Extraction on working fluids
Experimental setup (Static compatibility test)

<table>
<thead>
<tr>
<th></th>
<th>HCFC22</th>
<th>HFC134a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature [°C]</td>
<td>Pressure [MPa]</td>
</tr>
<tr>
<td>Inlet of compressor</td>
<td>21.7</td>
<td>0.40</td>
</tr>
<tr>
<td>Outlet of compressor</td>
<td>72.3</td>
<td>1.77</td>
</tr>
<tr>
<td>Outlet of condenser</td>
<td>40.8</td>
<td>1.30</td>
</tr>
<tr>
<td>Outlet of additional condenser</td>
<td>37.8</td>
<td>1.25</td>
</tr>
</tbody>
</table>
Results (outlet of compressor)

- After compression
  - Gas HFC134a is partially miscible to mineral oil
  - Gas HCFC22 is miscible to mineral oil
Results (outlet of additional condenser)

- Liquid HCFC22 is miscible to mineral oil
- Liquid HFC134a is almost immiscible to mineral oil
The visualization equipments are set at:
- Inlet of the compressor
- Outlet of the condenser
- Outlet of the additional condenser
Visualization equipment and experimental conditions

<table>
<thead>
<tr>
<th></th>
<th>HCFC22</th>
<th></th>
<th>HFC134a</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature [℃]</td>
<td>Pressure [MPa]</td>
<td>Temperature [℃]</td>
<td>Pressure [MPa]</td>
</tr>
<tr>
<td>Inlet of compressor</td>
<td>13</td>
<td>0.319</td>
<td>22</td>
<td>0.207</td>
</tr>
<tr>
<td>Outlet of condenser</td>
<td>35</td>
<td>1.50</td>
<td>35</td>
<td>0.93</td>
</tr>
<tr>
<td>Outlet of additional condenser</td>
<td>34</td>
<td>1.45</td>
<td>29</td>
<td>0.89</td>
</tr>
</tbody>
</table>
At the outlet of AC, liquid HFC134a is immiscible to oil so that oil droplets flow with refrigerant.

At the inlet of the compressor, oil is separated from gas refrigerator for both cases.
The working fluid extraction equipments are set at:
- Inlet of the compressor
- Outlet of the condenser / the additional condenser
Results

- Mineral oil was extracted for all cases
- Oil circulation was confirmed
- Circulation behaviors were different for each refrigerant

<table>
<thead>
<tr>
<th>Condition</th>
<th>Oil mass [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outlet of condenser / additional condenser</td>
</tr>
<tr>
<td>HCFC22</td>
<td>0.16</td>
</tr>
<tr>
<td>HCFC22+AC</td>
<td>0.25</td>
</tr>
<tr>
<td>HFC134a</td>
<td>0.74</td>
</tr>
<tr>
<td>HFC134a+AC</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Values are listed for reference.
Outline of the presentation

Chap.1 Introduction

Chap.2 Operation of Air-conditioning Systems by Proposed Methodologies

Chap.3 Circulation of Immiscible Mineral Lubricant Oil in an Air-conditioning System

Chap.4 Application: Performance of a Hot-water Supply System Utilizing Wasted Heat of an Air-conditioning System

Chap.5 Conclusion
Objectives

- Apply proposed methodologies to hot water supply:
  - Confirm improvement of overall efficiency including cooling and hot water supply
  - Rather than cooling efficiency
Experimental setup (Circuit chart)

Cold water → Temperature controlled bath → Desuperheater → Refrigerant pass

24℃ → Condenser → Valve → Evaporator → 27℃ Air

Existing air-conditioning system

35℃ Air → 65℃ Hot water

Air → Compressor → Valve → Water pass

27℃ Air → 65℃ Hot water

Existing air-conditioning system
Results (Performance)

- Optimal refrigerant charge increases with a desuperheater
- Cooling ability does not change with/without a desuperheater
- Cooling COP decreases with a desuperheater
- Overall energy efficiency improves with desuperheater
### Results (Mollier diagram)

The table below summarizes the results for both cases:

<table>
<thead>
<tr>
<th>Case</th>
<th>Amount of hot water supply [kW] (max)</th>
<th>Amount of heat exchange [kW] (max)</th>
<th>Cooling COP (max)</th>
<th>Overall energy efficiency (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without desuperheater</td>
<td>—</td>
<td>13.4 (14.2)</td>
<td>3.25 (3.31)</td>
<td>3.25 (3.31)</td>
</tr>
<tr>
<td>With desuperheater</td>
<td>7.40 (7.56)</td>
<td>13.0 (13.6)</td>
<td>2.77 (3.08)</td>
<td>4.35 (4.73)</td>
</tr>
</tbody>
</table>

The Mollier diagram illustrates the thermodynamic processes for both cases: with and without desuperheater.
Outline of the presentation

Chap.1  Introduction

Chap.2  Operation of Air-conditioning Systems by Proposed Methodologies

Chap.3  Circulation of Immiscible Mineral Lubricant Oil in an Air-conditioning System

Chap.4  Application: Performance of a Hot-water Supply System Utilizing Wasted Heat of an Air-conditioning System

Chap.5  Conclusion
Conclusion

- Proposed methodologies are validated
  - Retrofitting an additional condenser improves energy efficiency
  - Replacing refrigerant improves energy efficiency
  - Not cause any problem

- Circulation of mineral oil was confirmed
  - Although mineral oil is immiscible to liquid HFC134a

- Applying the methodology as hot water supply system utilizing wasted heat from air conditioning systems improves overall energy efficiency
  - Although cooling COP was decreased
  - More refrigerant was required for optimal operation