Discussion on environmental impact evaluation method of cooling and heating mechanical refrigeration system

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Contents

1. Refrigeration systems and their impact on the environment

2. Various types of environmental impact evaluation indicators and methods

3. Discussion on environmental impact evaluation method of mechanical refrigeration system
Contents

- Refrigeration systems and their impact on the environment
- Various types of environmental impact evaluation indicators and methods
- Discussion on environmental impact evaluation method of mechanical refrigeration system
1. Refrigeration systems and their impact on the environment

- **Refrigeration system definition**
  - In which refrigerant components are interconnected and composed of a closed refrigeration circuit, the refrigerant endothermic and exothermic in the loop.
  - Include heat pumps, absorption systems, preclude water and air refrigerant system.

- Refrigerated Merchandiser
  - (35-5°C)

- Air-cooled chiller
  - (25-53°C)

- Household refrigerator
  - (35-6°C)

- Water-cooled chiller
  - (5-38°C)

- Heat pump water heater
  - (25-38°C)

- Condensing Unit
  - (50-15°C)

- Refrigerated truck air conditioning
  - (35-5°C)

- Modular air conditioner
  - (25-38°C)

- Multi-type air conditioner
  - (25-38°C)

- Household air-conditioning
  - (-10-40°C)
1. Refrigeration systems and their impact on the environment

- Development of refrigeration and air conditioning industry in China

  - The world's largest refrigeration and air conditioning producing country
  - The world's second largest refrigeration and air conditioning consuming country.
  - Great progress has been made in product variety, size, technical, performance and quality, etc.

Refrigeration and air conditioning industry development contract of China in 20 years

1. manufacture; 2. output (million); 3. export (million)

- 1989 = 2010

- Development brought great impact to the environment
1. Refrigeration systems and their impact on the environment

- **Ozone depression**

- **Global warming**

**Global sea level trend**
1. Refrigeration systems and their impact on the environment

- Development of refrigerant

After three stages development, refrigerant is developed towards environmental-friendly at this monument. (energy saving, environmental protection, low-risk)

- First generation 1830-1930s whatever worked ethers, CO₂, NH₃, SO₂, HCOOCH₃, HCs, H₂O, CCl₄, CHCs, ...

- Second generation 1931-1990s safety and durability CFCs, HCFCs, HFCs, NH₃, H₂O, ...

- Third generation 1990-2010s ozone protection (HCFCs), HFCs, NH₃, H₂O, HCs, CO₂, ...

- Fourth generation 2010- global warming zero/low ODP, low GWP, short $\tau_{\text{atm}}$, high efficiency
1. Refrigeration systems and their impact on the environment

- Environment impact of refrigeration system
  - Positive effect
  - Negative effect

Urgently call for research in the environment impact evaluation method of refrigeration system
Contents

- Refrigeration systems and their impact on the environment
- Various types of environmental impact evaluation indicators and methods
- Discussion on environmental impact evaluation method of mechanical refrigeration system
2. Various types of environmental impact evaluation indicators and methods

- Ozone Depression Potential (ODP)
  - Degree of the atmospheric ozone depression.
  - Using the value of R11 as the reference, simplify derived by the calculation model

\[
ODP = \frac{\text{global ozone depression caused by unit mass of substance } X}{\text{global ozone depression caused by unit mass of R11}}
\]

- Global Warming Potential (GWP)
  - Degree of refrigerant impacting on global warming.
  - Using the value of R11 as the reference 1.0 in the past, generally written as HGWP to show the difference.
  - Using the effect of 100 years CO2 as the reference in recent years, and making CO2 GWP equal to 1.0 to calculate GWP of various refrigerants.

Relate to refrigerant impact on ozone depression and global warming
2. Various types of environmental impact evaluation indicators and methods

- **Total Equivalent Warming Impact (TEWI)**
  - Used to evaluate the impact on global warming of a refrigerant system running several years.
  - TEWI is called general warming impact. It consists of two parts:
    - **Direct impact:**
      - direct effect as refrigerant losing to atmosphere
      - effect as refrigerant leakage
      - effect as incomplete refrigerant recovery
    - **Indirect impact:**
      - indirect effect of carbon dioxide emission generated by the energy needed for the refrigerant system running in its life cycle.
    - **Total impact:**
      - sum of direct impact and indirect impact
  \[
  \text{TEWI} = \text{leakage loss effect} + \text{recovery loss effect} + \text{energy effect} \\
  = GWP \times L \times n + GWP \times m \left(1-\alpha_{\text{recovery}}\right) + n \times E_{\text{annual}} \times \beta \\
  = GWP \times \left(L \times n + m \left(1-\alpha_{\text{recovery}}\right)\right) + n \times E_{\text{annual}} \times \beta
  \]
2. Various types of environmental impact evaluation indicators and methods

- **Life Cycle Climate Performance (LCCP)**

  Similar as TEWI, is also used to evaluate impact of refrigerant and energy consumption on global warming of a refrigerant system running in life cycle which should consider the following two factors:

  1. Impact associated with energy used by productions of HFC and their raw materials (such as electricity and various fuels), and it is called embedded energy (E).
  2. Impact of any by-product generated in the production process as greenhouse gas emission, it is known as emission difficult to collect (fugitive emissions) F.

  \[
  LCCP = (GWP + E + F) \times (L \times n + m (1 - \alpha_{recovery})) + n \times E_{annual} \times \beta \\
  = TEWI + (E + F) \times (L \times n + m (1 - \alpha_{recovery}))
  \]

  Relate to impact on globe warming as refrigerant and energy consumption of system running in life cycle, not relate to impact of resource consumption.
2. Various types of environmental impact evaluation indicators and methods

- **Environmental safety comprehensive assessment method**
  (from LEED-NC Standard)

Comprehensively considering GWP, ODP, and atmospheric lifetime of refrigerant, calculating the impact as the refrigerant emission into the atmosphere:

\[
\Pi_{\text{ODP+GWP}} = \text{LCGWP} + \text{LCODP} \times 100000 \leq 100
\]

\[
\text{LCGWP} = \left[ \text{GWP}_r \left( L_r \times L_i + M_r \right) R_c \right] / L_i
\]

\[
\text{LCODP} = \left[ \text{ODP}_r \left( L_r \times L_i + M_r \right) R_c \right] / L_i
\]

Where:

- **LCGWP** — Life-cycle direct global warming potential index
- **LCODP** — Life cycle ozone depression potential index
- \( L_r \) — one year refrigerant leak rate (percentage of the amount of refrigerant charge, the default value is 2%)
- \( M_r \) — Termination-of-life refrigerant loss rate (percentage of the amount of refrigerant charge, the default value is 10%)
- \( R_c \) — refrigerant charge of Per ton cooling capacity, the default value is 2.5 pounds
- \( L_i \) — equipment life, and the default value is 10a

Relate to refrigerant leakage impact on ozone layer depression and global warming in the system life cycle, not relate to impact of energy and resource consumption.
2. Various types of environmental impact evaluation indicators and methods

- **Environmental safety comprehensive assessment method**

  The calculated value is out of the limitation for refrigerant that ODP is not zero but very little

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>GWPr</th>
<th>ODPr</th>
<th>Rc</th>
<th>Li/a</th>
<th>Lr/%</th>
<th>Mr/%</th>
<th>LCGWP</th>
<th>LCODP</th>
<th>IODP+GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410a</td>
<td>1890</td>
<td>0</td>
<td>1.8</td>
<td>15</td>
<td>2</td>
<td>10</td>
<td>90.7</td>
<td>0.0000</td>
<td>90.7</td>
</tr>
<tr>
<td>R22</td>
<td>1780</td>
<td>0.04</td>
<td>2.1</td>
<td>15</td>
<td>2</td>
<td>10</td>
<td>112.1</td>
<td>0.000252</td>
<td>137.3</td>
</tr>
<tr>
<td>R123</td>
<td>76</td>
<td>0.02</td>
<td>1.7</td>
<td>23</td>
<td>0.5</td>
<td>10</td>
<td>1.2</td>
<td>0.00032</td>
<td>33</td>
</tr>
<tr>
<td>R134a</td>
<td>1320</td>
<td>0</td>
<td>2.05</td>
<td>23</td>
<td>2</td>
<td>10</td>
<td>65.9</td>
<td>0.0000</td>
<td>65.9</td>
</tr>
<tr>
<td>R152a</td>
<td>124</td>
<td>0</td>
<td>2.5</td>
<td>15</td>
<td>2</td>
<td>10</td>
<td>2.6</td>
<td>0.0000</td>
<td>2.6</td>
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<td>NH3</td>
<td>1</td>
<td>0</td>
<td>2.5</td>
<td>23</td>
<td>2</td>
<td>10</td>
<td>&lt;1</td>
<td>0.0000</td>
<td>&lt;1</td>
</tr>
<tr>
<td>CO2</td>
<td>1</td>
<td>0</td>
<td>2.5</td>
<td>15</td>
<td>2</td>
<td>10</td>
<td>&lt;1</td>
<td>0.0000</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
2. Various types of environmental impact evaluation indicators and methods

- **Naturalness**

  A new evaluation used to evaluate refrigerant a method using the existing evaluation criteria and indicator as correlation parameters.

  \[
  \varepsilon_{\text{naturalness}} = (a_1 Z_{\text{Toxicity}})^{\tau_1} (a_2 Z_{\text{Flammability}})^{\tau_2} (a_3 Z_{\text{Environmental protection}})^{\tau_3} (a_4 Z_{\text{synthetic}})^{\tau_4}
  \]

  where:

  - \(a_1, a_2\) — refrigerant leakage coefficient factor
  - \(a_3\) — coefficient factor related to leakage, wastage, recycling and other factors
  - \(a_4\) — related to synthesis coefficient factor
  - \(Z\) — weight
  - \(\tau_1\) — toxicity rating index
    - when non-toxic, \(\tau_1 = 0\);
    - when toxic, \(\tau_1 = 1\), refrigerant can also be divided according to toxicity rating index
  - \(\tau_2\) — flammability rating index
    - non-combustible, \(\tau_2 = 0\); micro-combustible, \(\tau_2 = 0.5\); combustible, \(\tau_2 = 1\)
  - \(\tau_3\) — Environmental protection rating index
    - when \(\text{HODP} + \text{GWP} \leq 100\), \(\tau_3 = 0\)
    - when \(100 < \text{HODP} + \text{GWP} \leq 1000\), \(\tau_3 = 1\)
    - when \(1000 < \text{HODP} + \text{GWP} \leq 10000\), \(\tau_3 = 2\), and so
  - \(\tau_4\) — relate to synthetic rating index
    - no-synthetic, \(\tau_4 = 0\); one time synthetic, \(\tau_4 = 1\), and so
2. Various types of environmental impact evaluation indicators and methods

- **Naturalness**
  
  - Degree of factors impact on human and the environment is not the same.
  - The relationship among the base is set to: $Z_{Toxicity} < Z_{Flammability} < Z_{Environmental\ protection} < Z_{Synthetic}$.
  
  - Basically consistent with result obtained with the traditional evaluation system.
  
  - Higher naturalness for natural refrigerant.
  
  - The range of choice will be very wide if Naturalness 0.5 is selected as standard.
  
  - The range of choice in the future will only be narrow using non-toxic, non-combustible, ODP=0, GWP less than 150 evaluation criteria.

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>$H_2O$</th>
<th>$CO_2$</th>
<th>R290</th>
<th>R600a</th>
<th>R152a</th>
<th>R123</th>
<th>R134a</th>
<th>R22</th>
<th>R11</th>
<th>R12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naturalness</td>
<td>1</td>
<td>0.78</td>
<td>0.73</td>
<td>0.71</td>
<td>0.59</td>
<td>0.51</td>
<td>0.41</td>
<td>0.34</td>
<td>0.16</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Relate to refrigerant safety, environment-friendly, and evaluate the refrigerant impact on the environment, not relate to energy and resource consumption impact.

--------- Propose new idea “system naturalness”
2. Various types of environmental impact evaluation indicators and methods

- **CO₂ Reduction rate Y**
  - Taking into account GWP and system refrigerant charge G.
  - CO₂ emission rate Y for refrigerant substitutes relative to the alternatives in the same unit, Y is calculated as follow:

\[
Y = \frac{G_{WP \text{ alternative}} \times G_{Be \text{ alternative}} - G_{WP \text{ alternative}} \times G_{alternative}}{GWP_{Be \text{ alternative}} \times G_{Be \text{ alternative}}}
\]

- When using R22 as alternatives:

\[
Y = \frac{G_{WP \text{ R22}} \times G_{R22} - G_{WP \text{ alternative}} \times G_{alternative}}{GWP_{R22} \times G_{R22}} = 1 - \frac{G_{WP \text{ alternative}} \times G_{alternative}}{GWP_{R22} \times G_{R22}}
\]

where: \(G\) — refrigerant charge
2. Various types of environmental impact evaluation indicators and methods

- **CO₂ Reduction rate Y**
  - Refrigerant $Y \geq 0.5$, could be seen as long-term alternative refrigerant.

Used to evaluate the impact for refrigerant substitutes relative to the alternatives on global warming, not relate to impact of energy and resource consumption.
2. Various types of environmental impact evaluation indicators and methods

- Comparison of existing environmental impact evaluation indicators and methods

  - All relate to refrigerant impact on the environment, some relate to the system and its life impact.
  - Energy consumption, resource consumption and environmental pollutant emissions in system life cycle were not all taken into account.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Lifecycle environmental impact of refrigeration and air conditioning products</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Refrigeration</td>
</tr>
<tr>
<td></td>
<td>Refrigration system</td>
</tr>
</tbody>
</table>
| ODP        | △ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ ^{
2. Various types of environmental impact evaluation indicators and methods

- **Life Cycle Assessment (LCA)**
  - **ISO**: method of summary and evaluate potential impact on the environment impact caused by all inputs and outputs of a product (or service) system in its entire life cycle.
  - **SETAC**: an objective process to evaluate the pressure on the environment of product, production process, and the activities, it seeks the opportunity to improve the environment impact and how to take advantage of this opportunity by evaluating energy and material use and waste emissions impact on the environment.

- **Life Cycle Assessment method**
  - definition of scope and purpose
  - inventory analysis
  - environmental impact assessment
  - improved analysis
2. Various types of environmental impact evaluation indicators and methods

- **Definition of purpose and scope**
  - Determine process of the evaluated product life cycle, which can be decomposed into multiple sub-process.
  - Use essentially a simplified evaluation model that the system boundary is divided artificially.

Simplified product life cycle system boundary of refrigeration and air conditioning system
2. Various types of environmental impact evaluation indicators and methods

- **Inventory analysis**
  
  quantify the environmental load, that means listing all raw materials and energy consumed in entire life cycle, including the production. It uses waste of a product as input, and lists all materials (including by-products) impact discharged in this process as output. Input and output is analyzed objectively and quantitatively, and the analysis should be run through the entire product life cycle process.

<table>
<thead>
<tr>
<th>Resource consumption</th>
<th>Energy consumption</th>
<th>Pollutant discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Resource</strong> ($A_1$)</td>
<td>$a_{11}$</td>
<td>Coal ($B_1$)</td>
</tr>
<tr>
<td>Material Resource ($A_2$)</td>
<td>$a_{21}$</td>
<td>Electricity ($B_2$)</td>
</tr>
<tr>
<td>Aluminum</td>
<td>$a_{22}$</td>
<td>Oil ($B_3$)</td>
</tr>
<tr>
<td>Copper</td>
<td>$a_{23}$</td>
<td>Liquefied petroleum gas</td>
</tr>
<tr>
<td>Plastic</td>
<td>$a_{24}$</td>
<td>Gasoline</td>
</tr>
<tr>
<td>Steel</td>
<td>$a_{25}$</td>
<td>Diesel</td>
</tr>
<tr>
<td>Glass</td>
<td>$a_{26}$</td>
<td>Nature gas ($B_4$)</td>
</tr>
<tr>
<td>Silicon material</td>
<td>$a_{27}$</td>
<td>Solar ($B_5$)</td>
</tr>
<tr>
<td>Limestone</td>
<td>$a_{28}$</td>
<td>Geothermal ($B_6$)</td>
</tr>
<tr>
<td>Other resource ($A_4$)</td>
<td>$a_{41}$</td>
<td>Other energy ($B_7$)</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
2. Various types of environmental impact evaluation indicators and methods

- **Environment impact analysis**
  - Qualitatively and quantitatively analyze the listed elements in the inventory analysis process, including the following steps:
    - classify the elements listed in the inventory analysis process;
    - qualitatively and quantitatively analyze the listed elements using environmental knowledge;
    - identify the significant environmental factors in each part of the system;
    - analyze and judge the identified environmental factors.

- **Improved analysis**
  - Compare the product environmental performance by determining the environmental load of product.
  - Redesign the product, constantly refine and improve.
  - Include quantitative and qualitative improvement, look forward to receiving program of product with minimal environmental impact.

LCA is a method to evaluate all potentially impact on the environment of all inputs and outputs in the entire life-cycle. It is difficult as related content is complexity and many critical evaluation data are difficult to obtain.
2. Various types of environmental impact evaluation indicators and methods

- Establishment of Refrigeration and air conditioning product LCA evaluation model

Life cycle environmental impact assessment model of refrigeration system product
Contents

1. Refrigeration systems and their impact on the environment
2. Various types of environmental impact evaluation indicators and methods
3. Discussion on environmental impact evaluation method of mechanical refrigeration system
Main problems of evaluation method

- **The environmental impact of refrigerant and refrigeration system**
  - whether to comprehensively consider the impact of refrigerant, energy consumption, resource consumption on the environment? ?
  - whether to use life cycle comprehensive environmental impact assessment of refrigeration system? ?
  - how to simplify life cycle environmental impact assessment ? ?
  - whether to consider the ODP parameter, or completely converted into CO2 emissions for the evaluation method? ?
  - whether to consider to put security and economic indicator into the system ? ?

- **Environmental impact assessment data determination**
  - refrigerant production process emission data ? ?
  - weight of each indicator coefficient in evaluation indicator ? ?
  - establishment of product environmental attribute database? ?
  - leak rate and recovery critical data of system determining method ? ?
  - energy consumption in system life cycle ? ?
3. Environment impact evaluation method of mechanical refrigeration system discussion

- Research program of the evaluation method
  - General objective
    - Study and propose scientific, rational, and complete evaluation methods, indicators and measurement methods
  - General plan
    - Form framework evaluation general principle
    - Propose evaluation requirements for different categories of products
  - General requirement
    - Comprehensively consider the environmental impact of refrigeration system (include the impact of refrigerant, energy consumption, resource consumption on the environment)
    - Comprehensively consider refrigeration system life cycle environmental impact assessment
    - Use a scientific, reasonable and simply method to evaluate
Research program of the evaluation method

- **Research content**
  - Comparative analysis of existing indicators and provision of new environment-friendly evaluation method
  - Analysis of indicator impact factor and its weight factor
  - Critical test and evaluation technology
  - Rationality validation of indicator
  - Database creation and analysis of indicator limit value

- **Form**
  - Establishment of the work group for ‘Environmental impact evaluation method for heating and cooling mechanical refrigeration system’

Looking forward to propose scientific, rational, comprehensive evaluation method, indicators and test methods through this research, to provide technical support for the standard drafting.
Thank You!