Harmonizing Life Cycle Climate Performance Analysis of Refrigerants

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Abstract: Searching for alternatives to high-GWP refrigerants became a major research topic for the air conditioning and refrigerant community, requiring a universal evaluation of the environmental impact caused by a refrigeration system charged with a specific refrigerant throughout the refrigerant life cycle. The life cycle climate performance analysis (LCCP) provides such evaluations, including major contributors to direct and indirect refrigerant emissions. In 2012, the International Institute of Refrigeration (IIR) formed a working party (WP) on this topic (called LCCP WP) to assess the merits of different methods used for evaluating the environmental impact of refrigerants, and to produce implementation protocols for these methods to be used by decision makers and refrigeration stakeholders. This paper provides details of the IIR LCCP WP's ongoing efforts. The LCCP is an important tool for analyzing refrigerants' environmental impacts and screening refrigerants with minimum overall environmental impacts when used for a specific application in a specific region. A globally harmonized approach for LCCP evaluation is needed.

Key Words: refrigerant, GWP, life cycle, climate performance, TEWI, LCCP

1 INTRODUCTION

Working fluids should not only satisfy thermodynamic requirements to efficiently deliver sufficient capacities, but should also have minimal environmental effects. Recent international concerns about global warming have resulted in the inclusion of hydrofluorocarbons (HFC's) in the category of greenhouse gases (GHGs) in the Kyoto Protocol (United Nation, 1998). These concerns generated interest in using low Global Warming Potential (GWP) fluids such as HFOs, hydrocarbons, ammonia, and carbon dioxide. Since the global warming contribution from refrigeration and air-conditioning equipment is composed of about 16 percent from direct emissions and 84 percent from indirect emissions (Heap, 2001), the climate performance of refrigeration and air-conditioning equipment during its life cycle is an area of concern. Its proper evaluation is a key factor in determining the impact of working fluids for specific application and geographic location, and will assist in determining next generation working fluids for refrigeration and air-conditioning systems.

In response to global warming concerns, the International Institute of Refrigeration (IIR) has been advocating environmentally friendly, safe, energy-efficient and cost-effective design, operation, and end-of-life management of refrigeration and air-conditioning systems. As part of these efforts, the IIR has collected, compiled and disseminated information related to direct emissions of GHGs from refrigeration systems, as well as GHG emission mitigation. Forming a working party to assess the advantages of different methods for evaluating the environmental impact of refrigerants, and to implement protocols for these methods, to be used by decision makers and refrigeration stakeholders, is a good opportunity to utilize the results of the IIR's efforts.

2 REFRIGERANT'S CLIMATE PERFORMANCE METRICS

The climate performance of a refrigerant during its life cycle depends on many aspects. There are three main contributing categories according to time progress: the refrigerant's manufacturing process from raw materials, refrigerant equipment usage, and refrigerant's recovery and recycling process at the end of its life. All of these processes include the refrigerant's direct emissions and the indirect emissions through energy usage. In order to evaluate the environmental effects of refrigerants during its life cycle, three major metrics have been developed and expressed in CO_2 equivalent greenhouse gas (GHG) emission.

2.1 Total Equivalent Warming Impact

Total Equivalent Warming Impact (TEWI) is one metric that examines the direct effects from refrigerant emissions over the life cycle of the system, as well as the indirect effects of GHG emissions associated with energy consumption to operate the system.

TEWI = Direct emission + Indirect emission (1)

From the early 1990s, researchers at Oak Ridge National Laboratory (ORNL) investigated the energy and global warming impacts of existing and alternative refrigerants to replace CFC and HCFC refrigerants by utilizing the TEWI as a metric (Fisher et al., 1991, 1994; Sand et al., 1997).

2.2 Life Cycle Climate Performance

Life Cycle Climate Performance (LCCP) adopts the same methodology to evaluate the direct and indirect environmental impacts of a refrigerants over its life cycle. While TEWI and LCCP both utilize a similar approach, the LCCP includes several omissions in TEWI studies. It includes GHG emissions during refrigerant manufacturing (such as embodied energy and trace greenhouse gas emissions associated with fluorocarbon production) and emissions lost at the end-of-life (EOL) of the refrigerants (Little, 2002).

LCCP = TEWI + Direct emission [chemical refrigerant emissions including atmospheric reaction products, manufacturing leakage, and EOL] + Indirect emission [energy consumption from chemical production and transport and EOL] (2)

2.3 Life Cycle Assessment

Life Cycle Assessment (LCA) extensively evaluates the environmental impact of refrigerants at each stage of the system's life cycle beyond either TEWI or LCCP. The LCA includes emission factors associated with raw material processes, entire manufacturing processes, product distribution, usage during product lifetime, maintenance, and EOL disposal process. The LCA concerns on not only air emissions but aslo water emissions, and solid waste. The ISO standard 14040 (2006) defines standardized methodologies for life cycle management.

2.4 Comparison

The major difference in LCAs from two other metrics is that LCA concerns about water emissions and solid waste in addition to air emissions while TEWI and LCCP only concern on air emissions, especially greenhouse gas emissions. Figure 1 graphically compares three above metrics in non-scale basis only focused on air emissions aspect. Additional emission terms considered from their respective left metric are shown as horizontal arrows. As shown, the TEWI is the simplest metric, the LCCP is a slightly improved version of TEWI, and the LCA is the most comprehensive approach when comparing the climate performance of technologies by including emission factors from components and product production, transport, and destruction. In order to improve the accuracy of the LCCP evaluation, many recent LCCP evaluations include various additional emission terms considered in LCA. Therefore, there is a common ground between the LCCP and LCA. Since the main concern of the current effort is evaluating and minimizing the global warming impacts of refrigerants in various systems and locations, the LCCP WP decided to focus on harmonizing the LCCP.

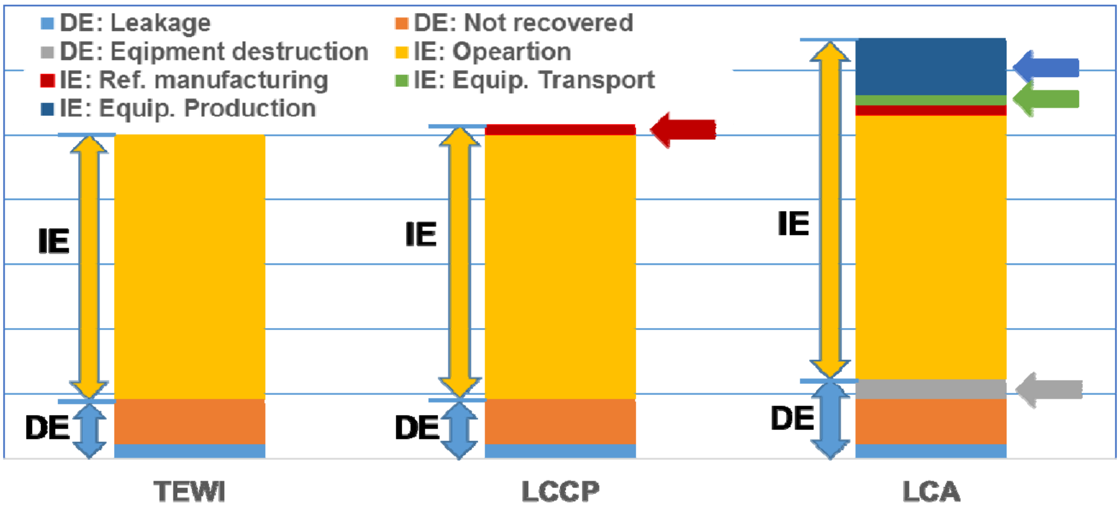

Figure 1: Comparison of climate performance metrics

2.5 Tools Available

Currently, there are several publicly available tools to evaluate the climate performance of refrigerants. IPU developed refrigeration utility software, Pack Calculation II, which can evaluate the TEWI and life cycle cost of refrigeration systems in various configurations (IPU, 2014). Regarding the LCCP tools, Papasavva et al. (2010) developed the GREEN-MAC-LCCP for automotive air conditioning systems sponsored by the Society of Automotive Engineers (SAE), and Zhang et al. (2012) developed the LCCP model for residential heat pumps sponsored by the Air-conditioning, Heating, and Refrigeration Technology Institute (AHRTI). These two LCCP tools are both Excel-based tools. SAE's GREEN-MAC-LCCP model included the direct emissions due to leakage from refrigerant production, transportation, and the indirect emission due to energy consumption needed to make refrigerant, components, end-of-life recycling, and recovery in addition to emission terms mentioned above. AHRTI's LCCP model includes the indirect impact of energy consumption used to manufacture and safely dispose the system and refrigerant in addition to terms mentioned above. Therefore, the LCCP models in these two tools added more emission terms used in the LCA analysis to the LCCP. In addition, Radermacher et al. (2014) developed a web version of LCCP tools for supermarket refrigeration and residential air source heat pumps sponsored by the ORNL. In addition to these publically available tools, most refrigerant, refrigeration, and air conditioning system manufactures also have exclusive tools which use different metrics and assumptions. Since using different metrics and assumptions result in a large difference in total emission results, a standardized LCCP evaluation methodology must be developed. Regarding the LCA assessment software, there are multiple number of tools available. For example, OpenLCA is an open source LCA software and is publicly available (2014). Among many commercial LCA tools, SigmaPro is the most outstanding one as it provides wide-ranging life cycle inventory databases and 15 different life cycle impact assessment methods (2014).

3 IIR's LIFE CYCLE PERFORMANCE WORKING PARTY APPROACHES

In order to assess the merits of different methods for evaluating the environmental impact of refrigerants and to produce standardized implementation protocols for these methods, the IIR formed "Life Cycle Performance Working Party (LCCP WP)" in 2012. Goals of this LCCP

WP are collecting information on direct and indirect emissions of working fluids for various applications from individual countries and from the current IIR's Working Party on "Mitigation of Direct Emissions of GHGs"; establishing the LCCP evaluation methodology applicable for refrigeration and air conditioning systems; evaluating how different assumptions selected by a user of these methodologies can affect the result of the assessment; assembling that information and distributing it amongst members of the Working Party and all IIR member states; and writing a booklet on the LCCP evaluation methodology developed so it can be available to the members of the Working Party, all IIR members, and non-members. In order to achieve these goals, the LCCP WP established its four year roadmap as shown in Figure 2. So far, this WP has met three times and formulated its process.

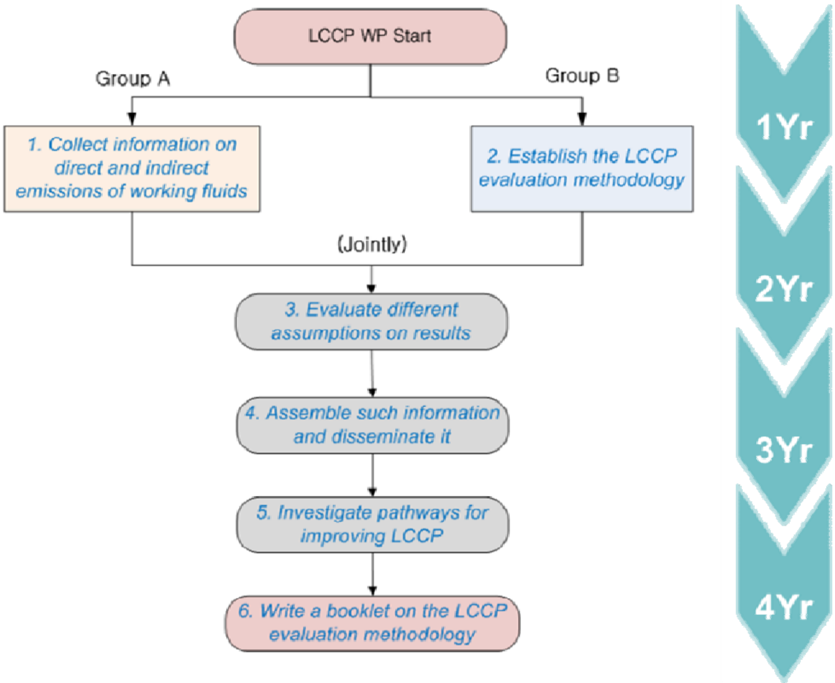

Figure 2: Four Years Roadmap of IIR's LCCP WP

3.1 Refrigerant's Climate Performance Evaluation

In order to assess the merits of different methods for evaluating the environmental impact of refrigerants and suggest a standardized methodology, the LCCP WP is planning to evaluate all of the following direct and indirect emissions.

For refrigeration and air conditioning systems, the following direct emissions from refrigerant leakage will be considered.

- Regular emissions from the system during its life time operation;
- Leakage during refrigerant and system manufacturing and transportation processes;
- Irregular emissions due to defects in products or installation, and accidental damages;
- Service emissions from servicing operations;
- Refrigerant loss at the EOL of the system during recovery and recycle processes; and,
- Atmospheric reaction products from the atmospheric breakdown of hydro fluorocarbons (HFCs).

Indirect emissions are due to power plant's GHG emission associated with energy consumption during the following processes:

- Refrigeration or air conditioning system operation during its lifetime;
- Refrigerant, component and system manufacturing and their transportation processes;

- EOL processes for refrigerants and system

Then total emissions of refrigerants will be calculated by summing up all these direct and indirect emission contributions.

It should be noted that the intention of the LCCP WP is not to provide the most accurate and complicated methodology, but rather to provide a simple methodology with minimum emission terms by not including less sensitive emission terms for more convenient use. Since results can differ based on the applications and locations due to different system characteristics, weather, operating hours, installation effectiveness, maintenance and repairs, and emissions in electric power generation, all evaluations must be conducted in a specific region.

4 CONCLUSIONS

There are several metrics to the refrigerant's life cycle climate performance with various assumptions and variations. Since the outcome of LCCP evaluation depends on what assumptions were made and which emission contributions were considered, a globally harmonized approach for LCCP evaluation is needed. As this methodology allows for detailed emission comparison among refrigerants in specific refrigeration systems and specific region, its evaluation and improvement options are also important for total emission reduction.

5 NOMENCLATURES

AHRTI	Air-conditioning, Heating, and Refrigeration Technology Institute
CFC	Chlorofluorocarbon
DE	Direct Emission
EOL	End-Of-Life
GHG	Greenhouse Gas
GREEN-MAC-LCCP	Global Refrigerants Energy and Environmental Mobile Air Conditioning Life Cycle Climate Performance
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbons
HFO	Hydrofluoroolefin
IE	Indirect Emission
IIR	International Institute of Refrigeration
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCCP	Life Cycle Climate Performance
ORNL	Oak Ridge National Laboratory
SAE	Society of Automotive Engineers
SEER	Seasonal Energy Efficiency Ratio
TEWI	Total Equivalent Warming Impact

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