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The Impact of Refrigerant Recycling on Reducing Carbon Emissions

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Abstract

Climate change is a serious global environmental problem currently facing humanity, and greenhouse gas emissions are an important cause of global climate change. Refrigerant recovery and treatment are of great significance in reducing greenhouse gas emissions. In order to reduce the ozone layer destruction and global warming caused by refrigerants, this paper analyzes the status quo of refrigerant recovery and disposal in the United States, the European Union and Japan, aiming to effectively manage refrigerants to reduce their environmental hazard. On the basis of in-depth industry research, this article focuses on the recovery and regeneration process of refrigerants as the main research object. Based on the LCCP climate performance model, a carbon emission assessment model for the refrigerant recovery and regeneration process is constructed. Taking the recovery and regeneration of automotive air conditioning refrigerant R134a as a case, its carbon emissions are calculated. The results indicate that in this case, recycling and regenerating the refrigerant can reduce equivalent CO_2 emissions by approximately 42%.

Key words: Climate change; refrigerant recovery; carbon neutrality.

1. The Impact of refrigerant recycling on reducing carbon emissions

Faced with the threat of climate change, controlling greenhouse gas emissions has become the primary task of protecting the global ecological environment. The refrigerant related policies formulated by the United States include: Standard for Recycle/Recover Equipment, Performance and Safety of Flammable Refrigerant Recovery and Recycling Equipment, Performance of Refrigerant Recovery, Recycling, and Reclaim Equipment. At the same time, it is legally stipulated that enterprises engaged in refrigerant recovery and utilization must obtain qualification certification from the United States Environmental Protection Agency in order to legally carry out refrigerant recovery. Currently, EPA recognized institutions for certification of recovery and recycling equipment include AHRI, UL (Air Conditioning, Heating, and Refrigeration Institute (AHRI) and Underwriters Laboratories (UL)).

The EU Regulation on F-gases, have been introduced by the EU to regulate the recycling, treatment, and destruction of ODS, with the aim of reducing HFCs within Europe. Similarly, refrigerant recovery, recycling, or destruction in Europe requires certification from an EU recognized certification body and qualification to carry out the above operations. Each member state has different requirements for the recycling and disposal of refrigerants based on compliance with EU regulations.

Japan's legislation on the recycling of chlorofluorocarbons includes CFC recycling and destruction methods, automobile recycling laws, household appliance recycling laws, etc. The regulation prohibits the direct discharge of refrigerant from air conditioning into the atmosphere. When dealing with and disposing of refrigeration air conditioners, it is an obligation to recover the refrigerant. The recycling and reuse of refrigerants in Japan is a national leading organization under the guidance of the government, with associations as the main body. It is the Japan Refrigeration and Air Conditioning Industry Association, which focuses on refrigeration recycling work in Japan, the Japan Refrigeration and Air Conditioning Equipment Industry Federation, which focuses on engineering services, and the Fluorinated Hydrocarbon Association, which mainly produces fluorinated hydrocarbon enterprises. It has been approved by the Machinery Intelligence Bureau of the Ministry of Economy and Industry of Japan to establish the Fluorine Refrigerant Regeneration Center, Starting from 1995, the qualification certification of refrigerant recovery and recovery technicians was carried out, and it was renamed as the Refrigerant Recovery Promotion Technology Center in 1988.

For unusable waste refrigerants, they are disposed of through destruction. The United States, the European Union, and Japan have rich ODS destruction technologies, achieving environmentally friendly disposal of ODS. Table 1 lists the current commercial destruction facilities in the United States, the European Union (some countries), and Japan, as well as the types of technologies used, as well as the capabilities and costs of ODS destruction. At present, there are 11 ODS commercial destruction facilities in the United States with a disposal capacity of 318 tons/year, and over 47 ODS commercial destruction facilities in the EU member states listed in the table have a disposal capacity of over 3600 tons/year, while there are 80 such facilities in Japan. Japan is currently the country known to have the most abandoned ODS disposal facilities.

Table 1. Refrigerant Destruction Facilities

different countries	Number of ODS facilities destroyed	Technology used	ODS Destruction Capability
America	11	Rotary kiln method Plasma method Fixed furnace unit Liquid injection unit method Cement kiln method Light aggregate kiln method	318 tons/year
Belgium	2	kiln process	-
The Czech Republic	1	kiln process	40 tons/year
Denmark	4	Catalytic cracking method	-
Finland	1	kiln process	545 tons/year
Germany	7	Hazardous Waste Incineration Reaction furnace cracking Porous reactor method	1600 tons/year
Hungary	5	kiln process	75 tons/year
Sweden	4	Air plasma method	100 tons/year
Japan	80	Rotary kiln method Nitrogen plasma arc method	36 tons/year

There are currently three main methods for evaluating carbon emissions. Global Warming Potential (GWP), evaluating the greenhouse effect of refrigerants, their ability to absorb infrared radiation, atmospheric lifespan, and time of use compared to CO_2; Total Equivalent Warming Impact (TEWI), proposed by the Kyoto Protocol, evaluates the climate performance of refrigerants operating in refrigeration systems for a certain period of time, calculates the direct/indirect emissions of refrigerants, energy consumption of refrigeration system operation, energy consumption of refrigeration system and refrigerant transportation, and the impact of total carbon emissions on the greenhouse effect during the process; The Full Life Cycle Climate Performance Index (LCCP) was proposed by Arthur D Little in 1999 to comprehensively evaluate the greenhouse effect of refrigerants and refrigeration systems during their operational life cycle. On the basis of TEWI, LCCP evaluation indicators include the production and recovery processes of refrigerants and refrigeration systems, as well as the impact of refrigerant decomposition products on the greenhouse effect.

With the upgrading of global environmental requirements and the deepening of environmental protection work, the refrigerant regeneration process has become an indispensable part of the refrigerant life cycle. The energy consumption and corresponding carbon emissions during the refrigerant regeneration process, as well as the evaluation of carbon reduction in the replacement of newly produced refrigerants with regenerated refrigerants, need to be explored. This article constructs a carbon emission assessment model for the refrigerant recovery and regeneration process based on the refrigerant recovery and regeneration technology and disposal process; Analyze the economic benefits of refrigerant regeneration treatment, including resource and energy consumption, environmental protection benefits, etc. during the refrigerant treatment process.

2. Method

2.1. Participants

Incorporate the indirect carbon emissions caused by the production, transportation, recovery, and regeneration of refrigerants, as well as energy consumption, into the full lifecycle model.

2.2. Design

The calculation process of the traditional carbon emission assessment method LCCP model is shown in Figure 2. The main data inputs in the calculation process include refrigerant leakage, production energy consumption of various system component materials, system cooling capacity, energy conversion efficiency ratio (customized cooling capacity/heating capacity to rated power ratio, abbreviated as energy efficiency ratio), and annual system operating meteorological parameters. The model does not include carbon emission calculations for refrigerant recovery and regeneration processes. In the refrigerant industry, in order to achieve the goal of carbon neutrality, the recovery and regeneration of refrigerants in units to be repaired or disassembled is one of the important ways to reduce carbon emissions. Therefore, this article attempts to supplement the carbon emission model of the refrigerant recovery and purification process with the traditional LCCP model, modeling two scenarios: refrigerant recovery and regeneration, and refrigerant non-recovery. Among them, in the case of refrigerant recovery and regeneration, different refrigerant recovery and regeneration disposal methods are modeled.

Refrigerant recovery and regeneration require the use of energy consuming equipment such as recovery/purification regeneration equipment and transportation equipment. At the same time, some refrigerant leaks inevitably occur during the process. Data such as energy consumption and leakage loss of each equipment are important input data for model solving.

During transportation, use, and other processes, direct leakage and discharge of refrigerant into the atmosphere result in direct emissions, while indirect emissions are caused by energy consumption during refrigerant production, transportation, recovery, purification, and regeneration. According to the SAE J2766-2019 Refrigerant Life Cycle Climate Performance Assessment Index, the direct and indirect emissions that cause greenhouse effects are shown in Table 1. The direct emissions are expressed as CO_2 equivalent emissions, and their values are evaluated based on

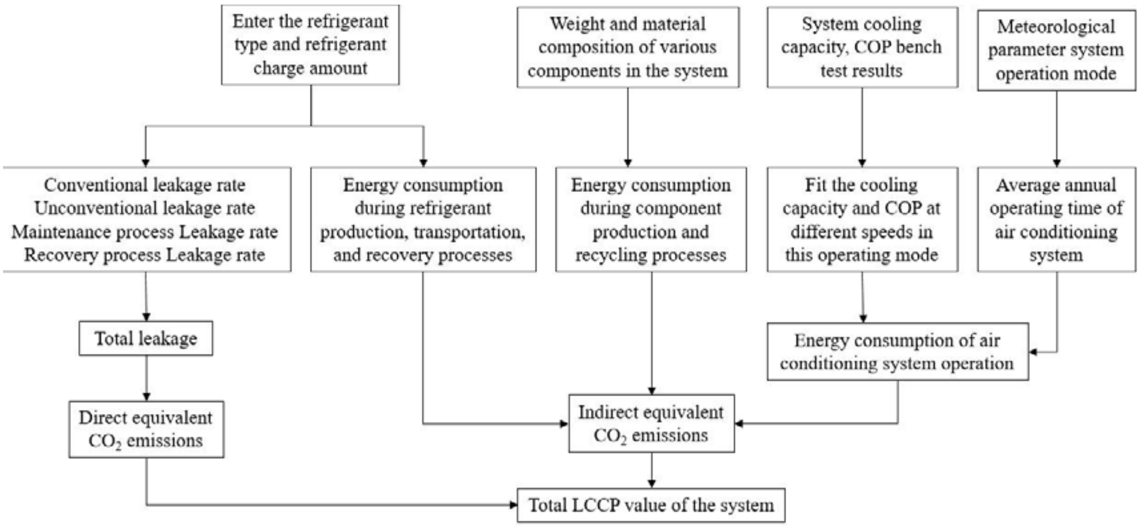

Figure 2. LCCP model composition

the global warming potential (GWP) of each chemical and the amount of refrigerant released into the atmosphere. Indirect emission calculation is related to the energy consumption of manufacturing, use, and treatment refrigeration systems, and the sum of CO_2 equivalent corresponding to this energy consumption is calculated. Refrigerant total equivalent CO_2 emissions = direct equivalent CO_2 emissions + indirect equivalent CO_2 emissions.

In the refrigerant recovery, purification, and regeneration process, some refrigerants directly leak into the external environment during the recovery and purification process, and the recovered refrigerant

There is still a small amount of residual refrigerant leaking into the environment during maintenance, which together constitute direct emissions that affect the greenhouse effect; The operational energy consumption of recycling and purification equipment constitutes indirect emissions that affect the greenhouse effect.

2.3. Materials

This article takes R134a, a refrigerant used in automotive air conditioning, as the research object to analyze its carbon emissions throughout its entire life cycle. The refrigerant charge capacity of an ordinary car air conditioner is about 600-900 g, and the car air conditioner normally loses 10% to 15% of the refrigerant every year. Every year, approximately 250 g of refrigerant is replenished for each car air conditioning repair.

The leakage of refrigerant is composed of the amount of refrigerant directly discharged into the atmosphere, including conventional leakage, unconventional leakage, maintenance process leakage, and recovery and regeneration process leakage. Referring to the leakage data related to the emission rating of refrigerant R134a in the automotive air conditioning system, it is estimated that the average conventional leakage of R134a is 115 g/a, the unconventional refrigerant leakage is 17 g/a. The leakage caused by professional maintenance is about 35 g, and the leakage caused by user self-repair is about 52 g. The refrigerant leakage during the recycling process of each scrapped vehicle is 100-450 g, and the actual leakage depends on the degree of refrigerant recovery and treatment.

2.4. Procedure

Assuming that the two extreme cases of refrigerant recovery are calculated separately: 1) The residual refrigerant in the automotive air conditioning should be recovered as much as possible, and the recovery rate of the agent is 90%, and only 10% is discharged into the atmosphere; 2) The refrigerant was not recovered and was directly discharged into the atmosphere, resulting in a refrigerant leakage rate of 100%. The service life of car air conditioning is consistent with the service life of the car. This article calculates the average of cars service life is 10 years. The indirect equivalent carbon emissions related to refrigerants are caused by the energy consumption of fossil fuels and electricity consumed in the production, transportation, recovery, purification, and other processes of refrigerants. This article takes the indirect equivalent CO_2 emissions caused by the production of R134a as 8 kg. The indirect equivalent CO_2 emissions in the refrigerant production process are 159 kg.

The calculation process of establishing a carbon emission assessment model for the refrigerant life cycle in a refrigeration system is as follows:

1) Obtaining the type and amount of refrigerant charged into the refrigeration unit;
2) Consult literature and industry materials to obtain data on conventional leakage, unconventional leakage, maintenance process leakage, and recovery process leakage of refrigerants. Calculate the equivalent CO_2 emissions directly emitted based on the total leakage of refrigerants;
3) Obtain the energy consumption of the production, transportation, recovery, purification, and regeneration processes of refrigerants, and calculate the equivalent CO_2 emissions indirectly emitted;
4) Calculate the total equivalent CO_2 emissions during the refrigerant life cycle. The extended refrigerant life cycle carbon emission calculation process is shown in Figure 3.

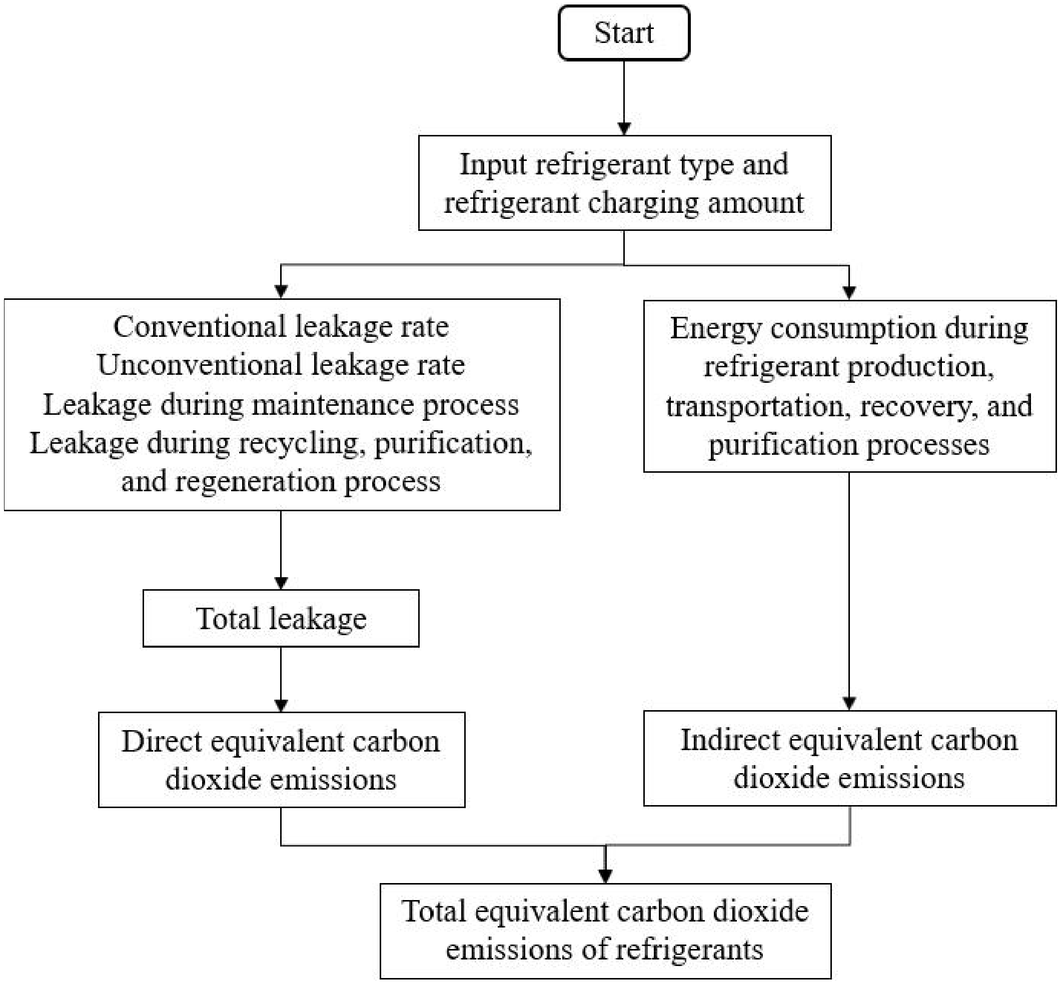

Figure 3. Flow chart of calculation of refrigerant life cycle model

3. Results

Based on the above model, the climate performance evaluation of the R134a refrigerant recovery and purification process was conducted, and the calculation results are shown in Figure 4.

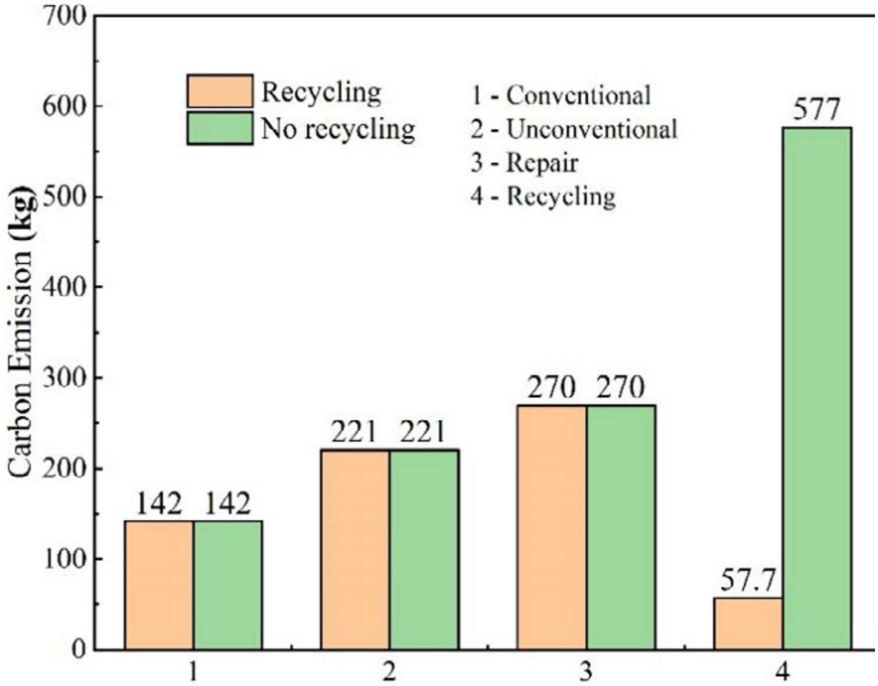

Figure 4. Carbon emissions caused by different refrigerant treatment methods

When recovering residual refrigerant from car air conditioning, the total equivalent CO_2 emissions of R134a are calculated as 704.6 kg, when the refrigerant is not recycled, the total equivalent CO_2 emissions of R134a are calculated as 1224.8 kg, recycling and purifying the refrigerant can reduce equivalent CO_2 emissions by approximately 42%.

4. Discussion

The widespread application of refrigerants has led to a large amount of emissions of Freon substances in the atmosphere, causing the problem of ozone hole and exacerbating the global greenhouse effect. To solve the environmental problems caused by the discharge of Freon substances, it is necessary to reduce refrigerant emissions. The most effective way is to establish a complete refrigerant recovery system and apply advanced refrigerant treatment technology to achieve refrigerant recovery and regeneration.

Developed countries and regions such as Japan, the European Union, and the United States started early on refrigerant recovery, with a large amount of recovery. The methods adopted by these countries are that the government and judicial authorities encourage refrigerant recovery and standardize the recovery process through legislation and the formulation of administrative regulations; Establish a refrigerant recovery organization within the refrigeration industry, develop recycling and regeneration technologies, and promote refrigerant recovery.

Finally, this article takes the process of refrigerant recovery and regeneration as the research object, and based on the LCCP climate performance model, constructs a carbon emission assessment model for the refrigerant recovery and regeneration process. Taking the recovery and regeneration of automotive air conditioning refrigerant R134a as a case, the carbon emissions are calculated. The calculation results show that recycling and purifying automotive air conditioning waste refrigerant can reduce equivalent CO_2 emissions by about 42%.

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