Computer Mathematical Statistics and Analysis on Automobile HFCs Reduction Path Using Big Data Technology

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Abstract. China has submitted an application to join the Kigali amendment to the Montreal Protocol. As the second largest hydrofluorocarbons (HFCs) consumer industry in China, the automotive industry is facing enormous pressure to reduce HFCs. This paper analyzes the current situation of HFCs use in the domestic automotive industry, and makes a simulation prediction of HFCs use data in the automotive industry from 2024 to 2030, analyze and evaluate the advantages and disadvantages of different technical routes. The relevant contents of this paper will provide reference for the formulation of HFCs reduction policy.

1. Introduction
On October 15, 2016, 197 parties to the global Montreal Protocol reached an agreement in Kigali on the reduction of the potent greenhouse gas, which lead to global warming [1]. In the Kigali amendment, 18 controlled substances HFCs were included in the control scope, including HFC-134a used in the automobile industry. The restrictions on HFCs production and consumption in different countries are shown in Table 1 below, and the total amount is calculated in CO₂ equivalent [2].

Table 1. HFCs production/consumption reduction schedule in the Kigali amendment

| Non-Article 5 parties | Article 5 parties – Group 1 | Article 5 parties – Group 2 |
|-----------------------|----------------------------|----------------------------|
| **Baseline**          | **Average HFC for 2011–2013+15% of HCFC baseline** | **Average HFC for 2020–2022+ 65% of HCFC baseline** | **Average HFC for 2024–2026+ 65% of HCFC baseline** |
| Freeze                | -                          | Freeze                     | Freeze                         |
| 10%*                  | 1 January, 2019           | 1 January, 2024            | 1 January, 2028                |
| 10%                   | 1 January, 2019           | 1 January, 2024            | 1 January, 2028                |
| 30%                   | 1 January, 2024           | 1 January, 2035            | 1 January, 2035                |
| 50%                   | 1 January, 2029           | 1 January, 2040            | 1 January, 2040                |
| 80%                   | 1 January, 2034           | 80%                        | 1 January, 2045                |
| 85%                   | 1 January, 2036           | 85%                        | 1 January, 2047                |

* For Belarus, Kazakhstan, the Russian Federation, Tajikistan and Uzbekistan, 25% HCFC component of baseline and different initial two steps (1) 5% reduction in 2020 and (2) 35% reduction in 2025

Group 1: Article 5 parties not part of Group 2
Group 2: Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and the United Arab Emirates
China belongs to Article 5 parties – Group 1 country, and its reduction nodes should comply with relevant requirements.

Automotive air conditioning (MAC) is one of the industries using HFCs, mainly used as refrigerant. Its annual usage is about 32,000 tons, which is the second largest refrigerant using industry in China, accounting for about one-fifth of the annual domestic consumption of HFCs. Some scholars in China have also conducted a systematic study on HFCS substitution policy in the automotive industry [3]. Developed countries reduce the use of HFCS in the automobile industry by making industrial use bans, strengthening system leakage control, and carrying out strict maintenance and scrap recovery supervision.

2. Calculation of HFCS consumption in automotive industry

At present, HFC-134a is the main refrigerant used in MAC in China. Some electric buses use R-410A or R-407C refrigerants because of greater demand for refrigeration and heating. Refrigerants used in major automobile products in China are shown in Table 2.

| Type     | refrigerant              |
|----------|--------------------------|
| Car      | HFC-134a                 |
| Truck    | HFC-125, HFC-32, HFC-134a|
| Fuel bus | HFC-125, HFC-32, HFC-134a|
| Electric bus | HFC-125, HFC-32, HFC-134a|

The refrigerant used in MAC is mainly added in new car production or product maintenance link [4]. The specific calculation formula is as follows.

\[
C_t = C_1 + C_2
\]

Where
- \(C_t\) Consumption of automobile industry
- \(C_1\) New car refill consumption
- \(C_2\) Maintenance charge consumption

2.1. New car fill consumption

The new car filling link consumption can be calculated by the amount of a single vehicle multiplied by the output. Because the refrigerant filling amount of car, truck, fuel bus, electric bus is different, we calculate them separately, and then sum them up.

\[
C_1 = \sum (a_{car} \times i_{car} + a_{truck} \times i_{truck} + a_{fb} \times i_{fb} + a_{eb} \times i_{eb})
\]

\(a_{car}\) Car production
\(i_{car}\) Filling capacity of single car
\(a_{truck}\) Truck production
\(i_{truck}\) Filling capacity of single truck
\(a_{fb}\) Fuel bus production
\(i_{fb}\) Filling capacity of single fuel bus
\(a_{eb}\) Electric bus production
\(i_{eb}\) Filling capacity of single electric bus

According to the industry data statistics, we take the relevant data in 2020, and the basic data values are shown in Table 3.
Table 3. Vehicle output and refrigerant filling data in 2020

| Model         | Production (thousand) | Filling quantity \( i \) (kg) |
|---------------|-----------------------|-------------------------------|
| car           | 19994                 | 0.536                         |
| truck         | 4239                  | 1.2                           |
| fuel bus      | 382                   | 2.1                           |
| electric bus  | 61                    | 3                             |

Substitute the data in Table 3 into Equation (2), after calculation, the total consumption of new HFCs in the automobile industry in 2020 is 16788.78 tons.

2.2. Maintenance charge consumption

The amount of maintenance link can be calculated by the market quantity, annual air conditioning maintenance proportion and other parameters. As car accounts for more than 80% of the total domestic ownership, we calculate the passenger car parameters as the representative in the calculation process. The actual usage data of maintenance link will be greater than the calculation data.

According to statistics, by the end of 2020, the number of cars in China has reached 281 million. The refrigerant consumption in the motor vehicle maintenance link is evaluated as follows.

\[
C_2 = O \times R \times M
\]

\( O \) Car ownership, 281 million
\( R \) Repair rate, 5%
\( M \) Maintenance filling amount, 536g

It can be calculated that the total consumption of the MAC maintenance industry in 2020 is 15,062 tons.

The consumption of HFCs in automobile industry in 2020 is 31851 tons.

2.3. Forecast of automobile industry consumption

Assuming that, the growth of new car consumption is calculated according to the annual growth rate of 3%, and the growth of maintenance consumption is calculated according to the annual car ownership. The HFCs consumption forecast for the automotive industry in 2021-2030 is shown in the Table 4 and Figure 1 below.

Table 4. Forecast of HFCs usage in automobile industry

| Year | Maintenance (ton) | New car filling (ton) | Total consumption (ton) |
|------|-------------------|-----------------------|-------------------------|
| 2020 | 15062             | 16789                 | 31850                   |
| 2021 | 16241             | 17292                 | 33533                   |
| 2022 | 17366             | 17811                 | 35178                   |
| 2023 | 18465             | 18346                 | 36811                   |
| 2024 | 19537             | 18896                 | 38433                   |
| 2025 | 20582             | 19463                 | 40045                   |
| 2026 | 21601             | 20047                 | 41647                   |
| 2027 | 22619             | 20648                 | 43267                   |
| 2028 | 23584             | 21268                 | 44852                   |
| 2029 | 24495             | 21906                 | 46401                   |
| 2030 | 25406             | 22563                 | 47969                   |
3. Analysis of HFCs Alternative Technology Path in Automotive Industry

HFC-134a refrigerant substitutes in automotive industry mainly include HFO-1234yf, HFC-152a, R290, etc. The technical parameters for the main alternative refrigerants are in Table 5.

| Refrigerant    | HFC-134a | HFO-1234yf | R-744(CO₂) | R-290 |
|----------------|----------|------------|------------|-------|
| molecular weight | 102      | 114        | 44         | 44.1  |
| The boiling point(1atm), ℃ | -26.2    | -29.5      | -78.4      | 41.9  |
| Ozone destroying potential (ODP) | 0        | 0          | 0          | 0     |
| Global Warming Potential (GWP) | 1430     | 1          | 1          | 20    |

3.1. HFO-1234yf

HFO-1234yf is the most important alternative of HFCs for MAC. It has been widely used in Europe, America and Japan. Currently, more than 100 million vehicles around the world use HFO-1234yf. Its main advantage is that it is similar to HFC-134a, and the air conditioning system does not need to be adjusted in a large range. Its disadvantage is that the refrigerant cost is high, and the cost of a single vehicle is increased by about 300 yuan. At the same time, due to its flammable grade of 2L, fire control requirements are put forward for production, maintenance and other aspects. Since the decomposition of HFO-1234yf will produce trifluoroacetic acid, its potential risk to the environment needs to be further evaluated.

3.2. R744

As a natural working medium, CO₂ has been partially applied in the field of industrial and commercial refrigeration. In the automobile industry, Volkswagen, BMW and Mercedes Benz have all developed MACs equipped with CO₂ and carried out small-scale mass production. The advantage of this technical route is that it can greatly improve the heating efficiency of the heat pump system in winter and solve the problem of EV's winter range. Its disadvantage is that the MACs needs to be redesigned and developed, which means the upfront investment cost is huge. At the same time, summer cooling efficiency is further improved.

3.3. R290

As a natural working medium, R290 has been widely used in home air conditioning. Its refrigerant refrigeration and thermal efficiency are higher than that of HFC-134a, and it is considered to be one of the refrigerants available in the future MAC. However, due to the combustible risk, its design and development safety specifications need to be further refined.
3.4. Evaluation of different technical routes
For China, the market is large enough to support the simultaneous development and application of multiple technologies. In the field of fuel vehicles and electric vehicles, the dominant factors in the choice of technologies are obviously different. Fuel vehicles only have refrigeration needs, can use HFO-1234yf for direct replacement, or HFC-152a for replacement, the cost is the main sensitive factor [5]. In the field of electric vehicles, the dual demands of cooling and heating need to be considered comprehensively. The working effect of HFO-1234yf and HFC-152a is not ideal. We can expect that R744, R290 and other technologies need to be further developed and applied.

4. Policy direction
At present, China has decided to accede to the Kigali Amendment to the Montreal Protocol, and the HFCs control process will gradually accelerate. In the refrigeration field, the replacement of HFC-134a in the automotive industry will become one of the important factors, but the high replacement cost leads to the automotive industry will certainly lag behind the household air conditioning and other industries. For the automotive industry, we recommend inclusion.

1. In the first phase, 2024-2028, the industry will be controlled at frozen levels through quota management. Through the construction of some demonstration projects, enterprises in the industry are encouraged to carry out partial replacement activities.

2. In the second stage, 2028-2034, it is expected to basically complete the replacement of HFCs filling in the production link through quota management, meanwhile, strengthen the management of maintenance link.

3. In the third stage, with the scrapping of most HFC-134A refrigerant models in 2034-2045, the maintenance consumption will gradually decrease to less than 20% of the industry consumption.

References
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