Technology Strategy by TRIZ Tools for Eco-Aircare Solution

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Abstract. Recently, air pollution issues such as particular matter or atmospheric aerosol particles have been raised around the world, especially in China and Korea. To cope with these environmental issues, companies are providing a variety of air care solutions to consumers. With the addition of energy regulations such as the Montreal Protocol, the Kyoto Protocol and the Paris Agreement, there is a greater possibility that contradictions exist between alternatives in addressing air pollution as well as existing energy savings. In particular, the technology related to refrigerant is the core technology of air conditioning equipment, and when developing a system, it is one of the important processes to understand the relationship between refrigerant characteristics and the components inside and outside the system. In this paper, the TRIZ is used to establish a technology strategy by conducting a case study on GWP refrigerants (low and high) and air conditioning equipment.

Keywords: Air-care solution · Refrigerant · Low GWP · Technology evolution · Ideality · Resource

1 Introduction

There is a growing number of consumers who consider air quality as a means of evaluating quality of life. Year after year, the demand for air quality is increasing. In the past, the perception that was limited to temperature has changed to the type of pollutant such as particular matter or atmospheric aerosol particles, and recently, attention has been paid to the level of the pollutant. As a result, companies have provided a variety of air care solutions to meet changing requirements.

In addition, requirements beyond countries, such as climate and environmental regulations, are driving changes in relevant markets and technologies. Particularly, the goal of reducing consumption and emissions for refrigerants is severely influential throughout products using refrigerants. If the country does not have the relevant technology or infrastructure, the country will soon lose own competitive edge in the market. It is necessary to prepare according to the situation in each country before the reduction targets and schedules set through the Kigali Amendment to the Montreal protocol arrive. According to the amendment, the schedule is divided into four groups,

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starting from the non-A5 countries in Fig. 1. The countries have long been actively involved in research and institutional maintenance of refrigerants. The countries and schedules covered by the group are listed in Table 1.

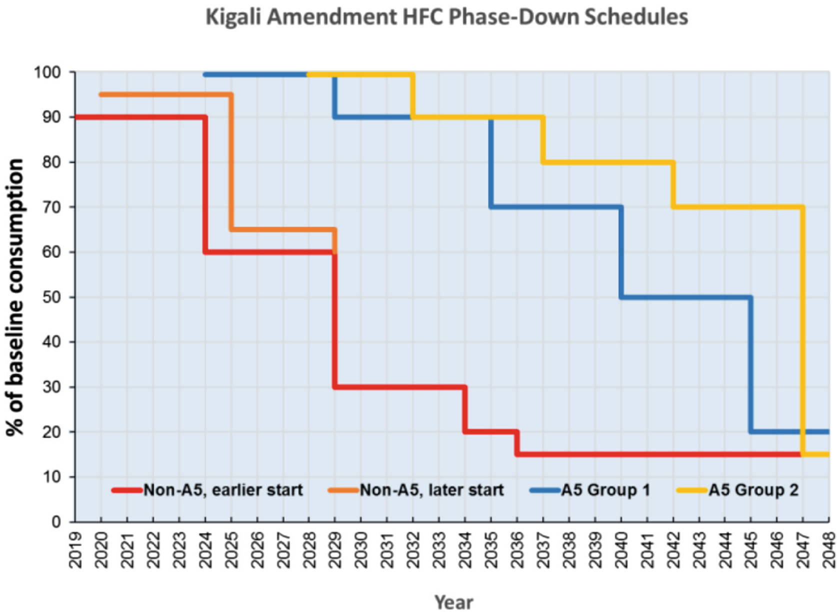

Fig. 1. Kigali Amendment HFC Phase-down for Classification of countries (Source: Reference [1, 2])

Table 1. Classification of parties and countries (Source: Reference [1, 2])

Classification of Parties	Year of HFCs Phase down Freeze	Countries
Non-A5, earlier start	Main group (2019)	45 Countries (included EU)
Non-A5, later start	Exceptions (2020)	Belarus, the Russian Federation, Kazakhstan, Tajikistan, Uzbekistan
Article 5 Group 1	2024	The 137 other Parties of the Montreal Protocol (included Republic of Korea, China)
Article 5 Group 2	2028	Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates

The EU has been implementing its own regulation since 2012, called the F-Gas Regulation. Air conditioners filled with 3 kg or less of refrigerant include only GWP750 (Global Warming Potential) since 2025. In addition, the refrigerant quota system has been registered since 2017. In United States of America, local government-led initiatives are being prepared, with guidelines similar to those in the EU. Japan is making all-out preparations under the initiative of the state, while China is conducting reduction activities according to the agreement schedule. Australia, the Middle East, South America and Southeast Asia are also preparing for regional cooperation [3].

Refrigerant use regulations have been an activity since the beginning of the development of refrigerants. As shown in Table 2, it has changed in the direction of reducing the harmful functions of refrigerants from initial refrigerants to alternative refrigerants.

Table 2. Trend of refrigerant characteristics (Source: Reference [4, 5])

Generation	Refrigerant	Toxicity[a]	Flammability[b]	ODP[c]	GWP[d]
1st Infant	Ammonia (R717, NH_3)	B	2	0	0
2nd Freon Era	CFC (R12) Chlorofluorocarbons	A	1	1	10900
	HCFC (R22) Hydrochlorofluorocarbons	A	1	0.055	1810
3rd Ozone protection	HFC (R134a) Hydrofluorocarbons	A	1	0	1430
4th Global Warming	HFO (1234yf) Hydrofluoroolefin	A	2L	0	<1

a Toxicity: A (Lower: no identified toxicity at concentrations $\leq$400 ppm), B (Higher)

b Flammability: 1(no flame propagation), 2L(Lower: max burning velocity <10 cm/s), 2L (Lower), 3(Higher)

c ODP: Ozone Depletion Potential, UNEP (2006). R11 = 1

d GWP: Global Warming Potential (100 year), IPCC 4th Assessment Report, (2007). CO_2 = 1,

The initial refrigerant was toxic and therefore high risk for the user. CFC (Freon) was developed in an effort to reduce the direct risks of toxicity, flammability, etc. And it has been used for a long time until fully phase-out in 2010. Since then, Cl (Chlorine) and F (Fluorine) components included in the CFC is known to adversely affect the environment, such as ozone depletion and greenhouse gas generation, has been developing a refrigerant in a direction to reduce this effect. Refrigerant-based systems have also been developed accordingly. Recently, the GWP has focused on finding a low (<750) or extreme low (<150) state.

Applicable alternative refrigerants appear in a pattern similar to the S-curve type in Fig. 2. Recently, HFO and HC refrigerants, which are emerging as alternatives, have excellent environmental performance, but there is a possibility that the risk is increased due to lower performance or flammability compared to existing refrigerants. Therefore, additional verification is needed to apply alternative refrigerants, and many companies are spurring related developments.

In order to maintain the performance of existing systems using alternative refrigerants, the costs of changing the system or investing in equipment must be considered. However, this is not an ideal solution from the idealistic view of TRIZ. Ideality, a key concept of TRIZ, can help you set goals so you can find the fundamental solutions to problems. In this paper, we will examine the direction of establishing technical solutions for related systems including refrigerants using TRIZ method. Through this, it was intended to be used in technology development strategy that secured sustainability.

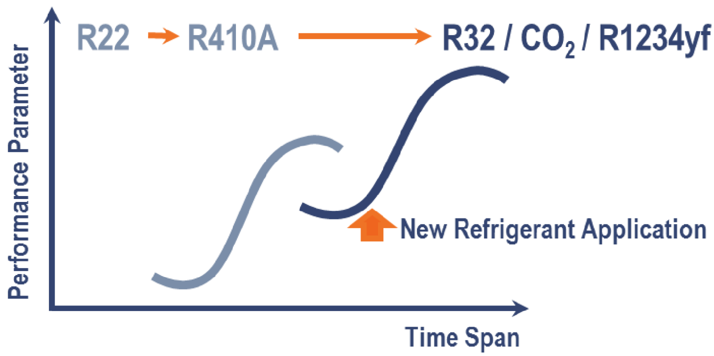

Fig. 2. S-curve of Refrigerant for air-conditioning system

2 Operating Time/Zone with Refrigerant Usage

In each country, we have established and implemented a policy to reduce the amount of used refrigerant and reduce the emission of existing refrigerants. Considering the lifetime cycle in which refrigerant is used, it is desirable to find the constraints and respond accordingly when a problem may occur.

In the case of existing refrigerants, six major greenhouse gases, CO_2, CH_4, N_2O, SF_6, PFCs, and HFCs, may be generated during the production or decomposition of the refrigerant, including Cl and F, which are ozone depleting substances.

From the standpoint of developing a product, there are three things about operating time of product. You can think about (1) products that have been on the market from the past to the present, (2) products that are in production, and (3) products that are under development or are in development. At each stage, specific measures are needed to reduce the use or reduce the emissions.

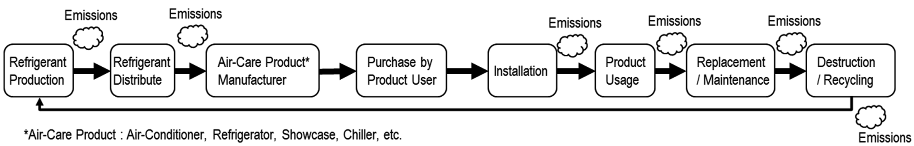

Fig. 3. Emission of refrigerant during air-conditioning system lifecycle

First, let's look at the emissions, that is, when the refrigerant is released into the air in Fig. 3.

From the point of view of a user using a product on the market, the product is purchased, installed, used, maintained, replaced or disposed of. The resolution direction may differ for each point of use. At the installation stage, a pipe joint structure without refrigerant leakage can be considered. Some products are used all year round, but some users use only one summer season. In this case, the refrigerant may be replaced during maintenance. It is important to consider whether there is a way to make it easier to replace the refrigerant or to prevent leakage. It is also necessary to consider how to reduce the period by checking the maintenance cycle. When disposing of the refrigerant or disposing of the product, it is necessary to check whether it can be recovered. In the case of waste water purifiers, some studies show that the remaining amount of refrigerant in the system is 40% [6].

After refrigerant was injected to the product, the refrigerant discharged to the atmosphere cannot be recovered. At the end of the product's lifecycle, recovery and treatment technologies are needed. Refrigerant may be released even when water is collected inside or mixed in the recovered refrigerant. Since the refrigerant is difficult to decompose, incineration may be performed using steam plasma. In this process, by-products such as CO_2, CO, and NO_X, which are other global warming materials, are generated, and the generated CF_4 is difficult to remove even by incineration. Therefore, it is necessary to secure a technology that suppresses the by-product generation itself and lowers power consumption. CF_4 is GWP 7390 and C_2F_6 is GWP 12200, which has 50,000 years and 10,000 years of atmospheric lifetime of refrigerant, respectively, causing secondary problems due to refrigerant disposal.

It can also be seen in terms of the space in which the refrigerant is present. It is possible to think of ways to prevent the leakage of indirect leakage between the coupling parts due to the two-phase refrigerant state connecting the pipelines through which the refrigerant flows. The atmospheric lifetime of the leaked refrigerant means the point at which the refrigerant components in the atmosphere naturally disappear. Therefore, it is conceivable to collect the refrigerant around the product before the refrigerant is discharged and after the discharge. In the case of flammable refrigerants, it is possible to consider how to spread rapidly in the space of use, so as not to form a cloud around the product. After being released into the atmosphere, one method may be to separate refrigerant gas from the earth's surface and the troposphere and between the troposphere and the stratosphere, using materials that react easily to the atmosphere.

3 Define Engineering System and Ideal System

It defines engineering system from the functional point of view and defines the fundamental reasons why the engineering system performs its functions. When the main function of the refrigerant is defined as absorbing or releasing heat, the refrigerant may also be defined as transferring heat from a heat source.

(1) Engineering System: Refrigerant (in Air-conditioning system)
(2) Main Function: Absorb Heat, Release Heat.

The ideal system for the above engineering system can be defined as a system that does not have refrigerant but absorbs or releases heat. Considering this ideal system, one can think break to psychological inertia. Making a refrigerant is not the desired result. What is your ideal goal? What is the desired result?

There is no refrigerant, but you need to think about whether absorbing heat is your ideal goal. We need to ask why absorbs the heat. For example, it can be considered to lower the temperature of the room or to maintain the temperature of the food. If your goal is to absorb heat constantly, you can think of ways to take advantage of other effects. The thermoelectric module using the Peltier effect is representative.

4 Ideality of Refrigerant

The definition of the equation of ideality that is commonly used by many people [7] is:

$$\text{Ideality} = \frac{All\ Useful\ effects}{All\ Harmful\ effects} \quad (1)$$

Among the methods of achieving the ideality of a technical system, defining an ideal component is one of the methods for achieving the ideal component while maintaining the whole system without change. This can be used to derive the ideality of the refrigerant [8]. Since the refrigerant exists as a component of the engineering system, such a air-conditioning system, if the ideal of the refrigerant is improved, the entire technical system can be closer to ideal system. Expressing the ideal of the refrigerant by the definition of the above equation is as follows.

$$\begin{aligned}&\text{Ideality of Refrigerant}\\&= \frac{Useful\,Function[Heat\,transfer\,efficiency + \ldots]}{Harmful\,Function[Environmental\,impact + Safety + \ldots] \times Cost[production + disposal + \ldots]}\end{aligned} \quad (2)$$

- Safety: Toxicity, Flammability, stable, treatment, lubricant, etc.
- Environmental impact: Ozone Deplete Potential, Global Warming Potential, decomposition product.

By using the ideality equation of the defined refrigerant, we can compare the ideality when using the existing refrigerant and the alternative refrigerant.

(1) If using existing refrigerant, If use base refrigerant (ex. R410A)

$$\text{Ideality of Refrigerant} = \frac{UF(constant)}{HF(toxicity + nonflammable + GWP(> 750)) \times constant\ cost} \quad (3)$$

(2) When using an alternative refrigerant, Alternative refrigerant (ex. HFC R32)

$$\text{Ideality of Refrigerant} = \frac{UF(constant)}{HF(taxicity + lower\,flammable + GWP(<750)) \times higher\ cost} \quad (4)$$

Refrigerant (R32 or R1234yf), which is considered as a strong alternative refrigerant, satisfies the existing thermodynamic characteristics and satisfies low GWP. However, it is flammable, which adds additional considerations in terms of user risk. Therefore, from an ideal point of view, the use of alternative refrigerants with low GWP is positive for the environment, and thus the Harmful function is reduced. Since additional costs for risk management, which were not present in existing systems, must be taken into account, it is necessary to prioritize in the short term and find the ideal refrigerant.

5 Multi-screen Thinking Approach for Refrigerant and Its Applicable System

In order to derive realistic goals from ideal system, it is necessary to examine the trends of related technologies and their surroundings. Use multi-screen thinking (MST), to identify applicable levels or resources to prepare in advance. Gather information to define how and where the engineering system absorbs or releases heat. The amount of heat absorption needed to keep a few bottles of beverage at the desired temperature is totally different from the amount of heat absorption required to maintain the temperature of a subway with dozens of people. These resources can then be used to step-by-step through the objectives of approaching ideality.

Resources can be found such as the time needed to maintain the temperature of the air during the day, the heat absorbed and emitted through the building's windows, the air density inside the building, the number of offices, and the size of the showcase. You can also find ways to reduce the cooling capacity load of an air-conditioning system inside a building by changing the size or number of windows in the building. There is also a case study to reduce the temperature inside the building by developing a polymer material that utilizes infrared heat radiation to absorb heat and reflects sunlight [9].

Information on climate change and seasons, such as temperature and humidity, in areas where the product is used, is also useful. In the Middle East, the sandy environment and temperature difference affect the operation characteristics of the compressor, which must consider both the oil and the refrigerant inside the compressor.

The stereotype of having to look for another refrigerant is an administrative contradiction because it cannot be used. The requirements need to be thoroughly reviewed, and whether the problem should be solved or not disappeared. If you look for the resources around you using multi-screen thinking, you can find where the refrigerant is used unnecessarily, or solve it by reusing the discarded refrigerant.

Therefore, the ideality of the air conditioning or refrigeration system, which is the supper-system, should be increased. Also, Technical development of refrigerant recovery and recycling systems should be carried out at the same time of maintenance or disposal. In addition, it is necessary to develop a technology for improving the compatibility with the compressor, heat exchanger, lubricant oil, etc., which are directly affected by the refrigerant. It is also necessary to review the compressor oil in anticipation of chemical changes with the refrigerant. It is also a way to reduce the CO_2 increase by minimizing the deterioration of efficiency due to the change in cooling capacity.

The ideality of the compressor, as the super-system of refrigerants, can be increased to improve the ideality of the whole system using refrigerants. For example, consider how to improve the insufficient function that can occur in a compressor. Low GWP (GWP 750 and below), which is currently considered as an alternative refrigerant, has a lower molecular weight compared to previous refrigerants, resulting in low suction density at the same compression volume [10]. Therefore, the lubrication is getting worse between the cylinders for compressing the refrigerant, the leakage may increase. If this is expressed as Su-field model, in Fig. 4. If solved using a 76-standard solution, an external environmental Su-field model that uses oil in the environment can be used. Consider increasing the oil supplied to the compression chamber.

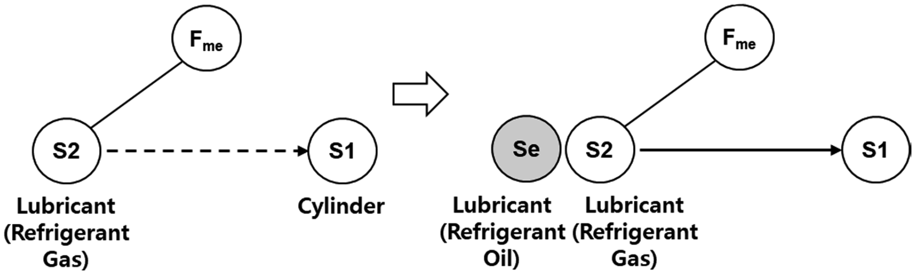

Fig. 4. Su-field Model of refrigerant gas and lubricant oil

6 Evolution of Materials (Refrigerant Composition)

It is possible to predict the core technology as a point of the evolutionary trend of the materials constituting the refrigerant. One of the evolutionary trends in technological engineering systems is the law of transition to higher-level systems [11]. This trend can be found in more detail in the materials and materials of technical systems. Most technical systems are made of the homogeneous material. This means they are used in combination with other materials or materials with opposite properties in order to perform better functions. It can be arranged as follows in Fig. 5.

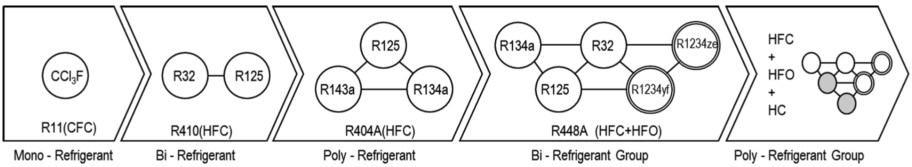

Fig. 5. Evolution of Refrigerant composition

In the case of ammonia, which is an early refrigerant, it is consisted of a single composition of molecular units, NH_3. The first CFC(R-11 or Freon), is also consisted of a single composition, CCl_3F. After phase-out the use of CFCs, HCFC or HFC refrigerants were developed and started to be used as single refrigerants. After that, two or three of composition were mixed with refrigerants having similar molecular composition (H, F, C). For example, in case of R-410 used in air conditioner, R-32 (CH_2F_2) and R-125 (CHF_2CF_3) are used in a mixture of 50:50. For R404A, a refrigerant used in a air-conditioner, is a refrigerant mixed with three refrigerants. Furthermore, it is possible to replace the existing refrigerant by developing a mixture of refrigerant groups having different molecular composition such as R448A [12]. According to this evolutionary trend, strategies for developing refrigerants that are suitable for product cooling capacity can be devised by diversifying the types of refrigerants mixed or optimizing the mixing ratio. In addition, depending on the ratio of refrigerants, it is change the cooling capacity (performance). So, conformity checks may be required between refrigerant and the product components (compressor oil, heat exchanger area, etc.) depending on the product's operating conditions. Considering the refrigerant usage scenario, it is also necessary to review the performance due to refrigerant filling, replacement or leakage from the equipment.

A list of Ideal status and technical strategy for refrigerant is below in Table 3. Considering the difference current with the target system, the actual technical approach direction was arranged by changing the target level through the step-back as shown in the table below.

Table 3. Ideal status and technical strategy for refrigerant

	Ideal status of refrigerant	Technical strategy goal
Ideal System	Refrigerant Free System	Improvement thermal capacity by thermoelectric effect (ex. Peltier effect)
Step Back 1	Using zero GWP, no concerned emission	Eco-friendly reusable nature
Step Back 2	Reuse or recycle whole refrigerant	Improvement of recycle equipment
Step Back 3	Allowed lower emission verified safety	Safety Risk assessment for flammable, high pressure refrigerant
Step Back 4	Only Using Low GWP Refrigerant using without System Change	Reduce refrigerant emission management and development devices
Step Back 5	Mixed Higher and Lower GWP Refrigerant with small system change	Find Specific Refrigerant for each application
Current	Gradually change usage rate of High GWP versus Low GWP refrigerant	Development of specific component for each application

7 Conclusion

In this study, in order to prepare a diversified solution to the tightening of refrigerant regulation, the technical approach to air-care solutions was derived using TRIZ. Instead of finding a solution in a situation where only requirements are given, an ideal system was defined in consideration of the internal and external components of the technical system from the TRIZ perspective. While the beneficial function of the thermodynamic performance is maintained, the direction in which the ideality of the refrigerant can be increased in the direction of eliminating the environmentally harmful function is examined. By multi-screen thinking approach, we examined not only the change trend of refrigerants but also the trends of the super-systems and sub-systems. Finally, the specific goal was found through step-back from the ideal system.

This study attempted to examine various alternatives beyond the solution focused on refrigerant development. Applying concepts of improving the ideality of components including refrigerant, the technical strategy was derived to improve the ideal of the whole system called Air-Care Solution. The results of this study can be used to construct roadmaps for future technologies in advanced and to prepare fundamental solutions.

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