BX14 - Carbon Emissions Reduction in the Refrigeration Air Conditioning Process in Bauxite Mining

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Abstract

This paper presents a pioneering case study in Brazil, carried out at Hydro Paragominas Bauxite Mine, whose objective is to reduce greenhouse gas emissions from refrigeration/air conditioning equipment, contributing to the sustainability of the process. Tests were carried out with a new fluid for air conditioning that reduces by up to four times the emission of elements that contribute to global warming potential (GWP). Called Ideal Eco Safe, the fluid is operating in MPSA appliances replacing commonly used R-22 and R-410A refrigerants. The replacement of these gases showed highly promising results, with the use of the new gas the devices are operating with less electrical current, with more efficiency, more safety and without change in performance. The operation began in December/2020, under the coordination of the refrigeration and air conditioning team, new assessments were carried out monthly to verify the performance of Ideal Eco Safe at different temperatures over time with the potential to achieve an annual reduction of up to 623 tonnes of CO_2 in the atmosphere.

Keywords: Carbon emission reduction, Refrigeration, Air conditioning, GWP, OWP.

1. Introduction

The refrigeration and air conditioning fluids currently used in the air conditioners installed in the plant of a mining in Pará (Hydro Paragominas), are the R-22 and R-410A. Table 1 indicates the chemical composition of these fluids and their relationship with the environment (ODP – Ozone Depletion Potential and GWP – Global Warming Potential).

Analyzing Table 1 we conclude that the R-22 fluid has non-zero ODP and GWP, contributing to ozone layer degradation and global warming (greenhouse effect). R-410A, although harmless to the ozone layer (ODP null because it does not have chlorine in its composition) is a greenhouse gas.

Table 1. Refrigerant fluids information.

Fluid	Chemical composition		Relationship with the Environment	
	Guy	Chemical formula	GWP [CO_2=1]	ODP [R-11=1]
R-410A	HFC - Hidrofluorcarbon	CH_2F_2/ CHF_2CF_3	2088	0
R-22	HCFC - Hydro**chlorine**fluorocarbon	$CHCLF_4$	1760	0.05

The countdown to full replacement of R-22 and R-410A has begun worldwide. According to the Montreal Protocol [1] and the Kigali amendment these fluids will have their import gradually reduced from 2020 until the shutdown in 2045.

Brazil has committed to adopt appropriate legislative and administrative measures and to cooperate in harmonizing appropriate policies to control, limit and reduce the emission of chemical substances that result in modifications or probable modifications of the ozone layer. To this end, IBAMA – Brazilian Institute of the Environment and Renewable Natural Resources has determined a schedule for the elimination of imports by Brazil. Figure 1 shows the schedule for eliminating the import of R-22 and R-410A.

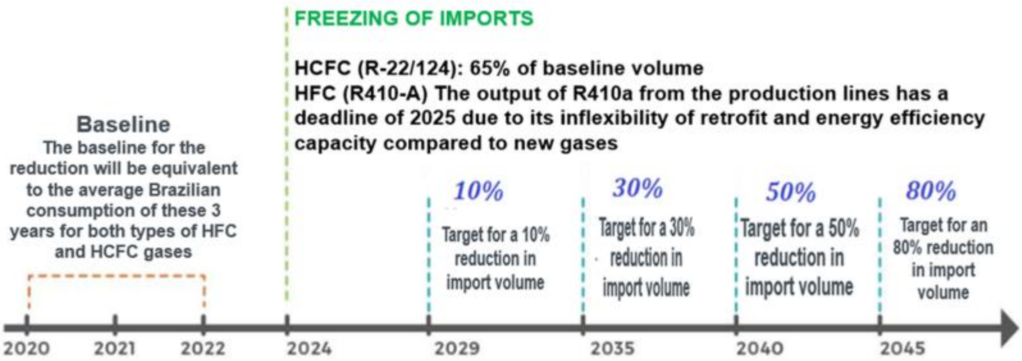

Figure 1. Timeline for elimination of HCFCS and HFCS [2].

Figure 1 shows that from 2024 the import volume of HCFC (R-22) will be 65 % of its average consumption between 2020 and 2022 (baseline). The volume of HCF (R-410A) will be 100 % of its average consumption. Subsequently, reductions in imports will be made until the shutdown in 2045.

It is then concluded that the refrigerant R-22, for suffering the greatest reduction initially in its importation, will not be found for acquisition with ease. The refrigerant R-410A, despite being a greenhouse gas, will have a longer term for its replacement. Thus, it is recommended immediately to replace R-22 with alternative refrigerants. The following chapters will present the alternative refrigerants, for application in equipment in use, with their advantages and disadvantages.

2. Theoretical Foundations

In 1987, the Montreal Protocol established regulations on refrigerants that affect the ozone layer and imposed targets for the elimination of CFCs. The term ODP (Ozone Layer Aggression Potential) was introduced and the refrigerant industry quickly introduced HFCs and their mixtures as substitutes for CFCs and HCFCs. The basic difference of these products is that HCFCs (hydrochlorofluorocarbons) still have the chlorine molecule harmful to the ozone and HFCs (hydrofluorocarbons) do not have chlorine [1]. It is then understood that the world starts to look differently at equipment that uses refrigerants with low OWP and GWP. Efficient equipment, which meets these requirements, are the new bets of the future.

HFCs are not controlled by the Montreal Protocol, these are listed under the Kyoto Protocol (1997). In 2005, the UNFCCC Convention (United Nations Framework Convention on Climate Change), implemented targets for these substances whose emissions must be limited or reduced. HFCs are considered long-term alternative fluids with respect to ozone depletion. As greenhouse gases, HFCs are controlled by the Kyoto Protocol, and a considerable number of countries are implementing regulations to control their use [2].

The ideal refrigerant is one that has excellent thermal properties, characterized by both presenting reduced values of GWP (Global Warming Potential) and zero ODP. This is the candidate for reducing the degradation of the environment and ensuring the good energy performance of a cooling system. The degree of toxicity, the level of flammability and the cost of the fluid are also preponderant parameters in this choice. In this case study, the soda used fits into almost all the ideal soda requirements, losing a little in the acquisition value issue.

According to the Intergovernmental Panel on Climate Change (Fourth assessment report, 2007), GWP measures the impact of a substance as a greenhouse gas, relative to the global warming effect of a similar mass of carbon dioxide over a specified time interval. The OWP- ODP (Ozone Depletion Potential), an index that indicates the damage that a substance can cause to the ozone layer. The ODP ranges from 0 to 1 and the closer to zero, the lower the impact on the ozone layer. The refrigeration and air-conditioning sector is responsible for 7 % of greenhouse gas (GHG) emissions, this figure is equivalent to 3.7 Gt of CO_2 per year. This equivalent annual emission could exceed 8.1 Gt in 2030, when the HVAC-R sector will contribute about 13 % to global emissions. Emissions from this particular sector are growing at a rate three times faster than the global average rate increase in greenhouse gas emissions. However, its impact can be minimized by environmentally friendly refrigeration technologies [1].

These technologies apply both to new manufactured systems and to old systems that support retrofit and application of new gases that are emerging in the market, as is the case of the ideal eco safe gas.

2.1 Alternative Refrigerants for R-22 Replacement

Table 2 describes the alternative refrigerants to R-22, their type and made in the environment (ODP and GWP), their availability in the domestic market and their safety class (flammability). Alternative refrigerants with low global warming potential are flammable (Class AL3 and A3) and therefore can only be applied in new systems for this purpose. The refrigerant fluids highlighted in red color in Table 2 were tested and evaluated by the engineering company Engie.

Table 2. Alternative refrigerants to R-22.

Alternative	Guy	GWP100 (AR)[5]	ODP	Availability	Safety Class
R-454C	HFO/HFC	150	0	No	A2L
N-20B	HFO/HFC	904	0	No	A1
R-444B	HFO/HFC/HC	300	0	No	A2L
R-1234yf	HFO	<1	0	Yes	A2L
R-290	HC	0	0	Yes	A3
R-410A	HFC	2088	0	Yes	A1
R-422	HFC	2473	0	Yes	A1
Ideal Echoes	HFC/HFO	450	0	Yes	A1
R-427A	HFC	2024	0	Yes	A1
R-438A	HFC	1890	0	Yes	A1
R-407C	HFC	1600	0	Yes	A1
R-449A (XP40)	HFO/HFC	1282	0	No	A1
R-449C (XP20)	HFO/HFC	1100	0	No	A1

When analyzing Table 2, it is concluded that the Ideal Eco Safe fluid presents the lowest GWP among the listed options.

The Ideal Eco Safe refrigerant makes use of solid manometric scale silicon dioxide particles dispersed in oil. Due to this characteristic, this refrigerant fluid is defined as nanofluid.
With the presence of solid particles, nanofluids have thermal conductivity much higher than that of common fluids such as R-410A, so there is usually better energy efficiency of refrigeration systems operating with this fluid.

The outsourced mining company carried out preliminary tests with the nanofluid in its laboratory where the external temperature reached a maximum of 33 °C. The refrigerant was applied in a 3 TR air conditioner with satisfactory results. Thus, it is suggested to apply the nanofluid in an air conditioner evaluating the results over time and with this result define by the substitution in the other conditioners.

2.2 General Information About Refrigerants Analyzed

The refrigerants R-449A, R-449C and Ideal Eco Safe are mixtures of HFCs with HFO – Hydro Fluorine Olefin which is an unsaturated organic compound. HFOs are being developed as the fourth generation of refrigerant, with 0.1 % GWP.

The Ideal Eco Safe refrigerant makes use of solid particles of silicon dioxide, on a gauge scale, dispersed in it. This characteristic of this refrigerant fluid will be treated in this work as nanofluid. Due to the presence of solid particles, nanofluids have thermal conductivity much higher than that of common fluids such as R-449A and R449C, so it is generally verified if better energy efficiency of cooling systems operating with this fluid [3].

Table 3 shows the substances that make up each refrigerant [4], the concentration of GWP, ODP, the safety class and the slippage (Glide), while Table 4 shows the advantages and disadvantages of each refrigerant.

Table 3. GWP, OWP, safety class and glide concentrations.

Fluid	Base Fluid Componentes			Φ (%)	GWP	ODP	Class	Glide
	Formula	Ashrae	Type					
Nano Fluid	CH_2FCF_3	R-134a	HFC	15 a 25	450	0	A1	Not Informed
	C_2HF_5	R-125	HFC	20 a 30				
	$CH2F_2$	R-32	HFC	20 a 30				
	C_3H2F_4	R-1234Yf	HFO	15 a 25				
	C_2H3F_3	R-143a	HFC	5 a 15				
R-449C	C_2HF_5	R-125	HFC	20	1147	0	A1	4.5 °K
	CH_2FCF_3	R134a	HFC	29				
	CH_2F_2	R-32	HFC	20				
	C_2H2F_4	R-1234Yf	HFO	25.7	1282	0	A1	4.6 ºK
R-449A	C_2HF_5	R-125	HFC	24.7				
	CH_2FCF_3	R-134a	HFC	29				
	CH_2F_2	R-32	HFC	23.4				
	C_3H2F_4	R-1234Yf	HFO	25.3				
R-22	$CHCLF_4$	R-22	HFC	-	1760	0.05	A1	0

Table 4. Alternative R-22 Advantages and Disadvantages.

Fluid	Advantages	Disadvantages
R-407C	GWP 7 % lower than that of R-22 / Available in Brazil.	Need to replace oil with cleaning of the SR – Cooling System.
R-449A (XP40)	GWP 27.16 % lower than R-22	Need to replace oil with SR cleaning – Refrigeration System / Needs Import
R-449C (XP20)	GWP 34.82 % lower than R-22	Need to replace oil with SR cleaning – Refrigeration System / Needs Import
R-427A	No oil replacement required / available in Brazil	GWP 15 % higher than R-22
R-438A	No oil replacement required / available in Brazil	GWP 7 % higher than R-22
Nanofluid	No oil replacement required / available in Brazil GWP lower than R-22 (Third part)	GWP to third part of R-22 / Not approved by ASSHARE / Sedimentation of solid particles may occur

Table 3 shows that the nanofluid presented the greatest reduction in GWP (74.43 %) in relation to the refrigerant R-22. The refrigerants R-449A and R-449C showed reductions in GWP of 27.16 % and 34.82 %, respectively. Currently the cost of R-22 refrigerant is still lower than other refrigerants, however the trend is that this relationship will be reversed in the coming years due to the reduction in the production and marketing of R-22.

Table 5. Costs of refrigerant fluids per kg.

Refrigeration fluid	Cost Per kg (base 05/2022)
R-22	$ 8.13
R-449A	$ 25.05
R-449C	$ 26.84
Nanofluid	$ 66.39

Table 5 shows the costs of R-22 and Nanofluid refrigerants used in this work.

2.3 Cooling System – Performance

The Coefficient of Performance (COP) is the most used parameter to indicate the performance of vapor compression refrigeration systems. The COP is defined as the relationship between the heat flow in the evaporator and the compression power, being determined through the Equation (1) [5].

$$COP = \frac{Q_{evap}}{W_{comp}} \tag{1}$$

where:
Q_{evap} Rate of heat through the evaporator
W_{comp} Required compressive power.

Analyzing the Equation (1) it is concluded that better performances of the vapor compression cooling system are obtained by intensifying the heat transfer in the evaporator and/or by reducing the compression power. In general, the performance of the refrigeration system depends directly on the characteristics of the compressor, the properties of the refrigerant and other equipment that make up the refrigeration system, as well as the operating conditions (evaporation and condensation temperature) and the maintenance of the system.

For example, a high overheating, pressure drops in the evaporator and in the suction line cause an increase in the specific volume of the refrigerant and therefore an increase in the power input requirements for the compressor, since the work in permanent regime is proportional to the specific volume, thus reducing the COP.

3. Methodology

As a methodology for conducting the field tests, it was necessary to select the following resources:

- Selection of equipment (HVAC/refrigeration);
- Cleaning of the equipment (streamers);
- Survey of the gas load existing in the equipment (Collection and weighing);
- Balance;
- Electronic thermometer (penta);
- Thermohigrometer
- Ammeter pliers;
- Complete manilfold set;
- Vacuum pump;
- Refrigerant gas R-22;
- Refrigerant gas R410A;
- Ideal ecosafe refrigerant gas;
- Double maintainers.

After the survey of the resources, the tests were started first analyzing the performance with the gas R-22 and after the measurements of this gas, the cleaning of the systems was carried out and a new gas load was added with ecosafe ideal refrigerant.

The measurement steps between R-22 and ideal safe had the following step by step and results as shown in the Figure 2 and in the Tables 6, 7 and 8.

4. Analysis of Results

The tests were carried out on air conditioners model Carrier 30 and 60 thousand BTUs that use R-22 refrigerants and work in the regime of 24 and 10 hours a day. Looking for other models of equipment that work with other types of gases, we also put in retrofit test 1 air-conditioning model Carrier of 36 thousand BTUs that works 10 hours could using the refrigerant R-410A.

Table 6 and 7 refer to the test performed in the air conditioning of 30 thousand and 60 BTUs that work in a 24 and 10 hour regime. Table 8 refers to the equipment of 36 thousand BTUs that works with the refrigerant R-410A.

Table 6. Performance analysis split Carrier 30 thousand BTUs work regime 24 hours / day.

Performance analysis Carrier Conditioner 30 thousand BTUs Evap. Model 42XCA030515KC / Cond. 38XCB030515MC					
Parameters	R-22	Ideal fluid ecosafe			
	Dec/20	Dec/20	Jan/21	Feb/21	mar/21
Air Temperature at the Evaporator Inlet (°C)	**21.4**	**21**	**21.2**	**21.5**	**21.7**
Air Temperature at Evaporator Outlet (°C)	**6**	**5.9**	**6**	**6.2**	**6.3**
Temperature: Air at condenser inlet (°C)	**30.7**	**30.4**	**30.5**	**31**	**31.2**
Temperature: Air at condenser outlet (°C)	**39.9**	**40**	**39.9**	**40.6**	**40.8**
El Current Compressor Trica (A)	**15.8**	**14.8**	**15**	**15.2**	**15.3**
Refrigerant Temperature in the Suction Line (°C)	**5.2**	**6,5**	**6,5**	**6.7**	**6.7**
Refrigerant Temperature in the Liquid Line (°C)	**35.8**	**32.62**	**32.78**	**32.9**	**33.88**
Suction Pressure (Psig)	**63**	**65**	**65**	**64**	**64**
Discharge Pressure (Psig)	**245**	**245**	**245**	**245**	**245**
Refrigerant Load (kg)	**1.8**	**1.65**	**1.65**	**1.65**	**1.65**
Condenser Temperature (°C)	**46.5**	**46.3**	**46.8**	**46.5**	**46.9**
Evaporator Temperature (°C)	**2.3**	**2.2**	**2.5**	**2.3**	**2.4**
Overheating (°C)	**2.9**	**3**	**2.9**	**2.9**	**3**
Subcoolness (ºC)	**10.7**	**10.5**	**10.7**	**10.9**	**10.8**

Table 7. Performance analysis split Carrier 60 thousand BTUs work regime 10 hours / day.

Performance analysis Carrier Evap Conditioner. /Cond. 60 thousand BTUs					
Parameter	R-22	Ideal fluid			
	Dec/20	Dec/20	Jan/21	Feb/21	mar/21
Air Temperature at the Evaporator Inlet (°C)	**23**	**21.5**	**22**	**22.7**	**23.2**
Air Temperature at the Evaporator Outlet (°C)	**10**	**9**	**9.5**	**9.8**	**10**
Temperature: Air at condenser inlet (°C)	**34,2**	**33.3**	**33.6**	**34**	**33**
Temperature: Air at condenser outlet (°C)	**44**	**43**	**43.3**	**43.7**	**43**
Compressor Electric Current (A)	**17,7**	**16.2**	**16.3**	**16.2**	**16.2**
Refrigerant Temperature in the Suction Line (°C)	**14,9**	**16.2**	**16.3**	**16.4**	**16.7**
Refrigerant Temperature in the Liquid Line (°C)	**35,8**	**28.6**	**28.8**	**29**	**29.3**
Suction Pressure (Psig)	**60**	**55**	**60**	**55**	**60**
Discharge Pressure (Psig)	**270**	**250**	**250**	**250**	**250**
Refrigerant Load (kg)	**2,8**	**2.7**	**2.7**	**2.7**	**2.7**
Condenser Temperature (°C)	**50,5**	**51**	**49.5**	**50**	**51.3**
Evaporator Temperature (°C)	**1**	**1.5**	**1.4**	**1.8**	**1.3**
Overheating (°C)	**13,9**	**14.2**	**14.4**	**14.9**	**14.2**
Subcoolness (ºC)	**14,7**	**14.9**	**15.1**	**15.3**	**‘4.8**

Table 8. Split performance analysis Carrier 36 thousand BTUs, refrigerant-R-410 A. Working regime 10 hours / day.

Performance analysis Carrier Evap Conditioner. 42XRV36CR / Cond. 38CCV036515MC					
Parameter s	**R-401A**	**Ideal fluid**			
	Dec/20	**Dec/20**	**jan/21**	**Feb/21**	**mar/21**
Air Temperature at the Evaporator Inlet (°C)	**22**	**21**	**21.6**	**21**	**21.8**
Air Temperature at the Evaporator Outlet (°C)	**5.3**	**6.3**	**6.2**	**6.3**	**6.2**
Temperature: Air at condenser inlet (°C)	**29.2**	**28.3**	**28.2**	**28.4**	**28.2**
Temperature: Air at condenser outlet (°C)	**42.8**	**41.6**	**41.8**	**41.4**	**42.4**
El CurrentisCompressor Trica (A)	**15.06**	**14.8**	**14.8**	**14.9**	**14.8**
Refrigerant Temperature in the Suction Line (°C)	**14.5**	**6.5**	**6.8**	**6.7**	**6.8**
Refrigerant Temperature in the Liquid Line (°C)	**19.9**	**32.62**	**31.77**	**32**	**31.9**
*Suction Pressure (Psig)	**100**	**65**	**65**	**66**	**65**
Discharge Pressure (Psig)	**170**	**145**	**145**	**145**	**145**
Refrigerant Load (kg)	**1.2**	**1.65**	**1.65**	**1.65**	**1.65**
Condenser Temperature (°C)	**45.5**	**46.5**	**45**	**46.2**	**45.5**
Evaporator Temperature (°C)	**-0.4**	**2.3**	**3**	**3.1**	**2.9**
Overheating (°C)	**14.9**	**4.2**	**3.8**	**4.3**	**4**
Subcoolness (ºC)	**25.6**	**25.8**	**25.7**	**26**	**26.3**

After the results of the application of the Ideal Eco Safe fluid in place of R-22 and R-410A that are described in the tables presented above. we can analyze and verify the following results:

1 – The conditioners are operating with lower electric current using the Ideal Eco Safe. Reduction in electric current of 7.4 % in relation to R-22 and 2 % in relation to R-410A.

2 – The air conditioners are operating with lower condensation pressure using the Ideal Eco Safe, being indicative of better efficiency.

3 – The air conditioners are operating with satisfactory thermal performance.

Regarding the environmental impact, the simulation was used in the graph below, using 460 kg of the ideal EcoSafe gas which is the annual amount of R-22 gas used in the company, comparing what would be the reduction with this same amount for R-22 or R 410A Gas.

Figure 2. GWP Reduction.

5. Final Considerations

For the ODP, the impact would only be with R-22 gas because it is an HCFC. Thus, because it is null, R410A and Ideal Eco Safe would not cause impacts on the Ozone Layer.

The Ideal Eco Safe refrigerant fluid proved satisfactory. The performance was evaluated for 4 months where the variations were irrelevant showing that the gas is ready for a safe and sustainable retrofit process without loss of efficiency in temperatures and problems caused to components to MPSA equipment. putting the company one step ahead on the path of reducing pollutants according to the latest Paris agreement that aims to strengthen the global response to the threat of climate change by reducing greenhouse gas emissions by 37 % below 2005 levels by 2025 and by 43 % by 2030.

6. References

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