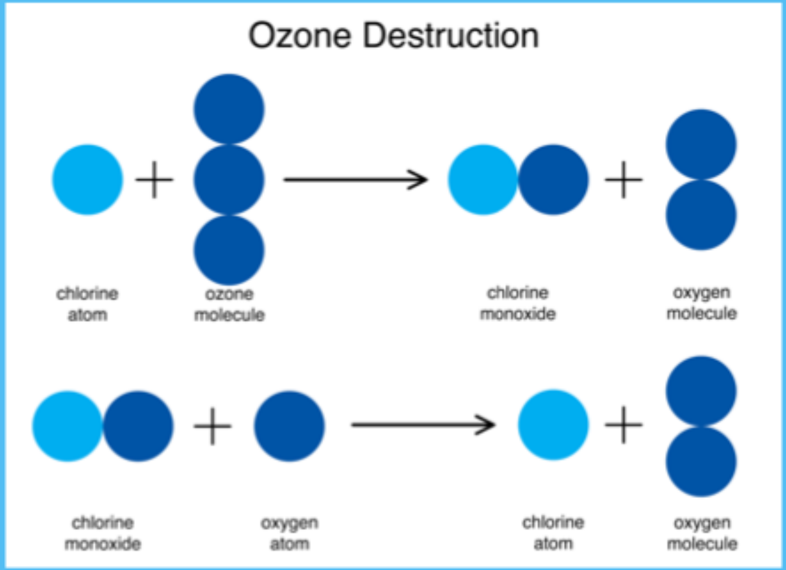
Implementation Of A Carbon Dioxide Refrigeration System As A Cogeneration Appliance And Replacement For Halocarbon-based Refrigeration Systems

OISIN DOHERTY | ETHAN PERRIN | ANDREW WANG | SONIA MURTHY | SOPHIA TEVOSYAN

HISTORY

History of CFCs

The history of the refrigeration industry began in the early 1920s with the synthesis of chlorofluorocarbons (CFCs) when large American corporations began seeking less toxic alternatives to the ammonia (NH_3), methyl chloride (CH_3Cl), and sulfur dioxide (SO_2) refrigerants that had been in use since the late 1800s.

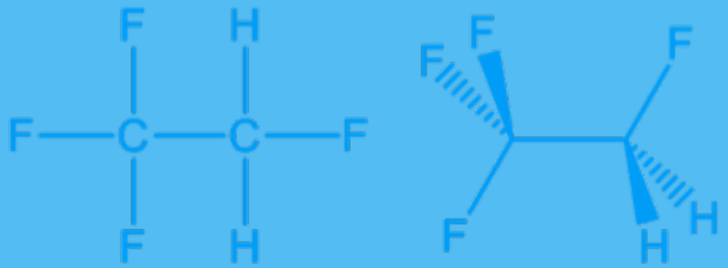


CFCs in the atmosphere are extremely effective ozone depleting substances because of the chlorine atom in the compound acts as a catalyst in the destruction of ozone.

History of HFCs

In response to the phasing out of CFCs as dictated by the Montreal Protocol, which was implemented in 1989, aerosol, refrigerator, and air conditioning companies quickly turned to HFCs. Although less energy efficient, HFCs lack the chlorine atom that catalyzes the harmful destruction of ozone.

HFC-134a



HFC-134a, also known as norflurane, is a haloalkane refrigerant. Current uses of HFC-134a include domestic refrigeration and automobile air conditioning.

Properties	
Molar Mass	102.03 g/mol
Melting point	-103.3 °C
Boiling point	-26.3 °C
Latent Heat of Vaporization	217.2 kJ/kg
Specific Heat Capacity	14.473 J/°K/mol

Problems

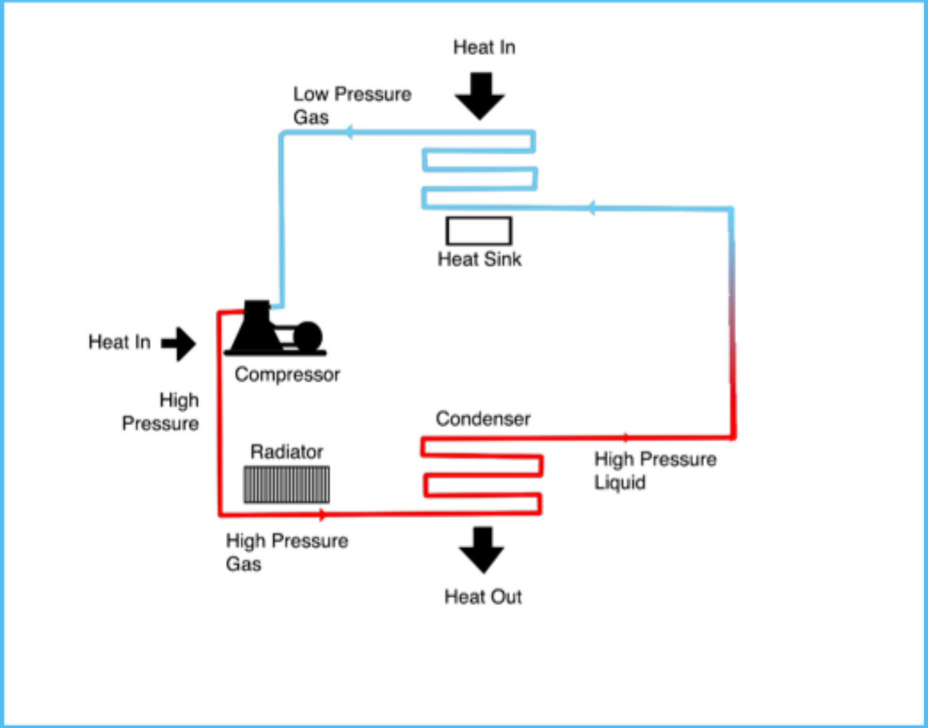
HFCs are very potent greenhouse gases.

According to current projections, HFCs could rise to 20% of total carbon dioxide equivalent emissions, resulting in the possible addition of 100 gigatons of carbon dioxide equivalent emissions and a 0.5 degree Celsius rise in global average temperature.

OUR OBJECTIVE

To develop a CO_2 refrigeration system to replace current common consumer HFC and CFC refrigerants in order to create a environmentally friendly, cogenerate CO_2 refrigeration system for consumer use.

REFRIGERATION

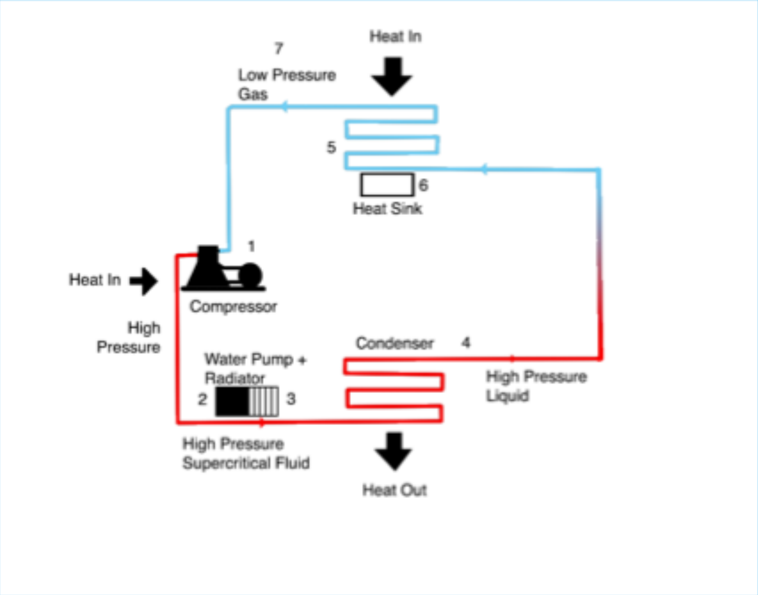


Vapor-Compression Refrigeration

A liquid refrigerant is evaporated into a vapor state, and through an endothermic reaction, heat is removed from the inside of the refrigerator

The warmer gas is now condensed into a liquid state, and through an exothermic reaction, heat is released outside of the refrigerator.

The evaporation process is what cools the inside of the refrigerator.



CO_2 Refrigeration

1. After the gaseous carbon dioxide passes through the evaporator, the compressor forces the CO_2 into a supercritical state under high pressures and temperatures.
2. The closed loop water pump system circulates cool water over the thin CO_2 tubing responsible for condensation (see 4). In an ideal system, the water circulates throughout the house to provide indoor heating before returning to the refrigerator.
3. The water radiator is the final step in the water cooling process, transferring the remaining heat from the water loop to the air.
4. Water cooling takes place in the radiative tubing, a long loop of high pressure tubing engineered for maximum heat transfer from the CO_2 to the circulating water, transitioning the CO_2 to a liquid state.
5. The cooled liquid CO_2 enters the inside of the refrigerator, where an expansion valve and wider tubing subjects the CO_2 to lower pressures, forcing it to expand into a gaseous state.
6. A heat sink assembly inside the refrigerator cooled by the gaseous CO_2 facilitates heat transfer with the air inside.
7. After absorbing heat from inside the refrigerator, the gaseous CO_2 returns to the inlet of the compressor for recompression.

CO_2

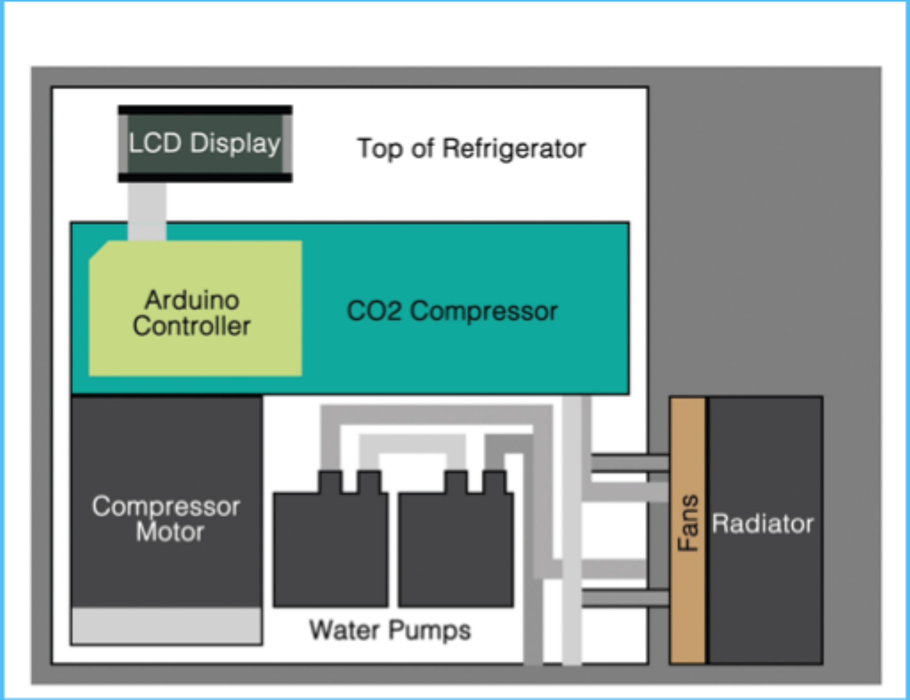
CO_2 is used as a refrigerant in liquid and solid form on the industrial scale, most notably in the food industry where they are employed during the transportation of frozen foods.

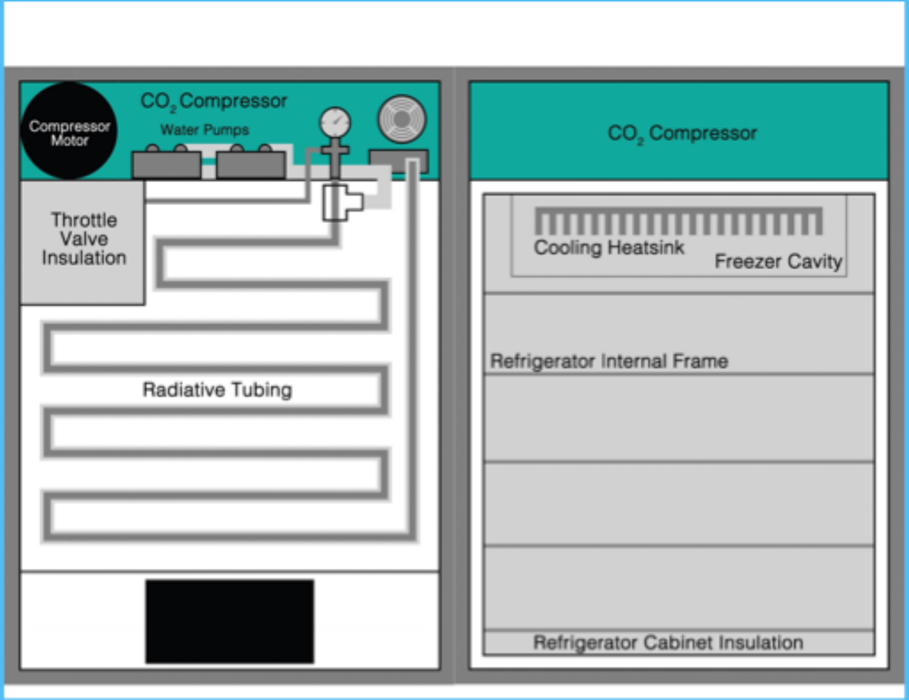
Properties	
Molar Mass	44.01 g/mol
Melting point	-78.0 °C
Boiling point	-56.6 °C
Latent Heat of Vaporization	574 kJ/kg
Specific Heat Capacity	37.135 J/°K/mol

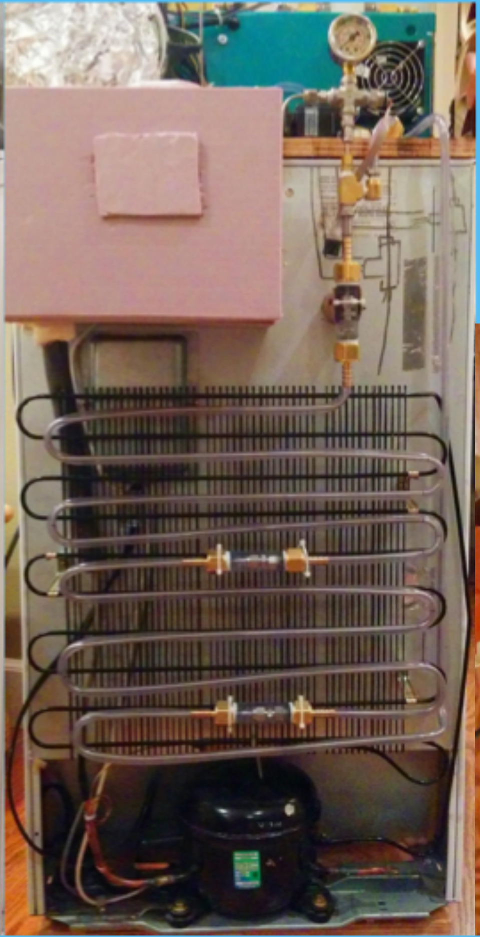
Benefits

- Cogeneration
  - Utilizing the high temperature of the system for heating water or space heating
- Better Performance
  - Higher specific heat capacity allows CO_2 refrigeration to cool to lower temperatures
- Removal of current HFC systems
  - Replacing current HFC refrigerant systems with CO_2 alternatives reduce the need for HFCs, phasing out a environmentally harmful gas from commercial use

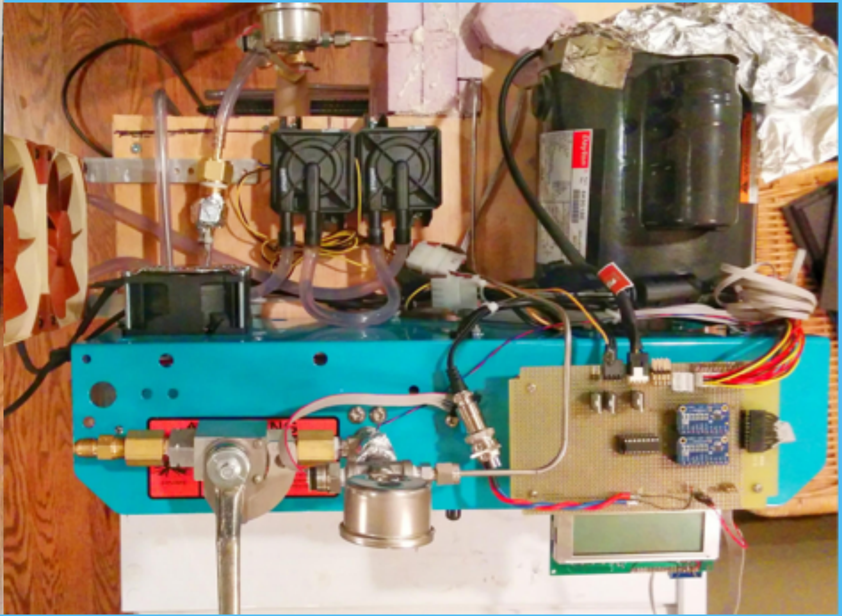
Design


LCD Display
Top of Refrigerator
Arduino Controller
CO2 Compressor
Compressor Motor
Water Pumps
Fans
Radiator

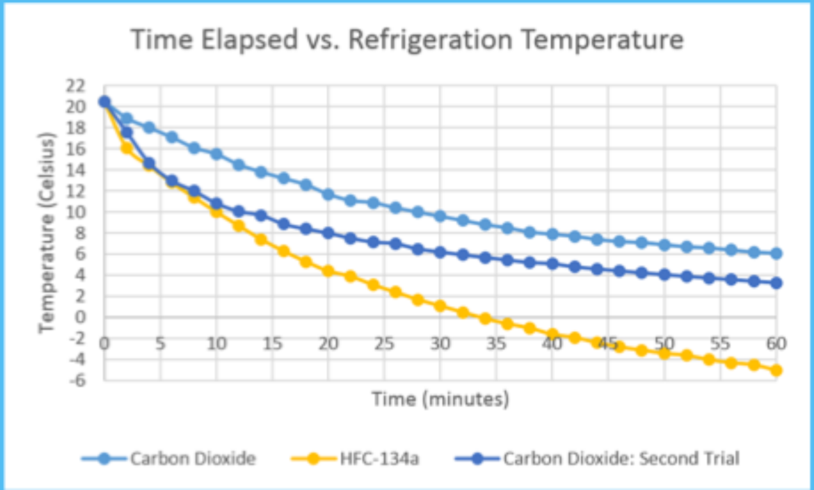

Compressor Motor
CO_2 Compressor
Water Pumps
Throttle Valve Insulation
Radiative Tubing
CO_2 Compressor
Cooling Heatsink
Freezer Cavity
Refrigerator Internal Frame
Refrigerator Cabinet Insulation

Build



Data



Itemized Power Consumption of the CO_2 Refrigerator	
Component	**Watts**
Idle Consumption	10.0
Radiator fans	5.8
Water pump	14.9
Compressor fan	17.0
Compressor w/ no load	88.3
Compressor w/ load	154.0
Watts saved from cogeneration	210.0
Net Total of Carbon Dioxide Refrigerator	80.0
Net Total of HFC Refrigerator	90.0

Calculations

Carbon Dioxide Refrigerator	
Power Consumption	233.6 kWh per year
Amount of Gas Used in Refrigerator Production	53 million metric tons of CO_2 per year
Standard HFC Refrigerator	
Power Consumption	262.8 kWh per year
Amount of Gas Used in Refrigerator Production	59 million metric tons of HFCs per year
Additional CO_2 Contributed by Carbon Dioxide Refrigerator	
130 metric tons of CO_2 (due to increased use of electricity)	
CO_2 Saved by Carbon Dioxide Refrigerator	
136 million metric tons of CO_2 saved annually	

NEXT STEPS

Further Research

Majority of improvements can be made in thermal design:

- Increase heat transfer between the cooled heatsink and the refrigerator
- Reduce losses in cooling power not contributing to cooling the heatsink
- Reduce heat output from other system components
- Increase thermal efficiency of the supercritical CO_2 heat exchanger
- Improve insulation of the refrigerator cabinet and reducing heat leaks

Conclusions

Despite the lower thermal performance of the carbon dioxide-based refrigerator, its utilization of CO_2 as a replacement for HFCs is able to significantly reduce the negative impact of refrigerants on the environment. If implemented on a global scale, the CO_2 refrigerator could potentially reduce greenhouse gas emissions by more than 136 million metric tons. Furthermore, its functionality as a cogeneration appliance will reduce electricity use in other aspects of the domestic setting, providing for 6% of annual space heating demands. While the prototype of the refrigerator is unrefined and therefore does not operate at maximum efficiency, mass-production of the appliance with further design optimizations could both lower its power consumption and increase its thermal performance to better match that of current refrigerators. Thus, the carbon dioxide-based refrigerator is less detrimental to the environment, and has the potential to reach and even exceed the performance of current refrigerators as a growing technology.