THE USE OF CO_2 AS A REFRIGERANT IN AUTOMOBILE AIR CONDITIONING SYSTEMS

Arman Zarae, Mechanical Engineering Senior | Dr. Birce Dikici, Mechanical Engineering Professor, Advisor

EMBRY-RIDDLE Aeronautical University
DAYTONA BEACH, FLORIDA

INTRODUCTION TO REFRIGERATION AND ENVIRONMENTAL CONCERNS

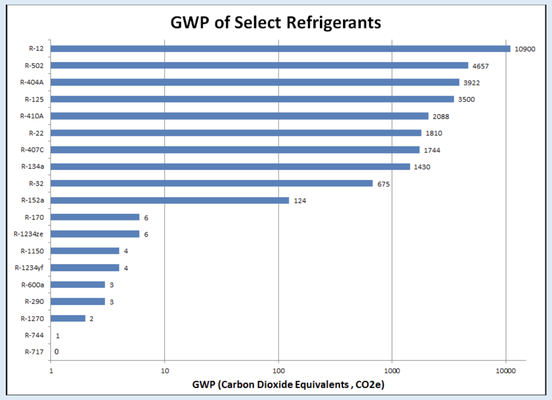
Refrigeration is the cooling of space, often accomplished to preserve food or increase human comfort. This process is achieved mechanically, typically with the use of a refrigerant. Refrigerants are chemicals which are driven through a system and experience changes of phase. The refrigerant and mechanical system will act together to direct heat either in to or out of the conditioned space.

Many refrigerants are environmentally damaging, especially for early classes of industrial refrigerants. The Montreal Protocol of 1987 banned the use of chlorofluorocarbons (CFC), a class of chemicals infamously responsible for producing marked areas of depression in atmospheric ozone.

Many alternatives have been developed and used with varying levels of success, like R-134a and R-1234yf. Here we will consider the case of carbon dioxide used as a refrigerant (R-744).

R-744 systems have been developed for use in a variety of settings, notably for the supermarket industry, with wide adoption in Europe. Also in Europe, increasing interest has been generated in the use of R-744 in automobiles. It is desirable for use because it is a naturally occurring substance, with a Global Warming Potential (GWP) of 1, and an ozone depletion rating of 0.

GLOBAL WARMING POTENTIAL OF VARIOUS REFRIGERANTS



HIGHLIGHTED FACTS

- HFC refrigerants have been proven responsible for creating 'holes' in the atmospheric ozone layer.
- European and Japanese companies have been early-adopters of R-744.
- Not all refrigerants are the same. Global Warming potential may vary from R-744's "1" to R-12's "10,900.
- R134a is a common refrigerant, with a GWP of 1430.
- Panasonic systems with R-744 are 25% more efficient than comparable systems with R-404A

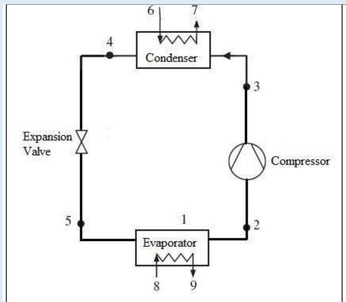


Figure 3. Direct Expansion CO_2 Subcritical Cycle [14]

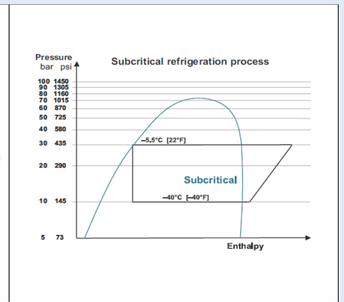


Figure 4. Direct Expansion CO_2 Subcritical Cycle In P – h Diagram [10]

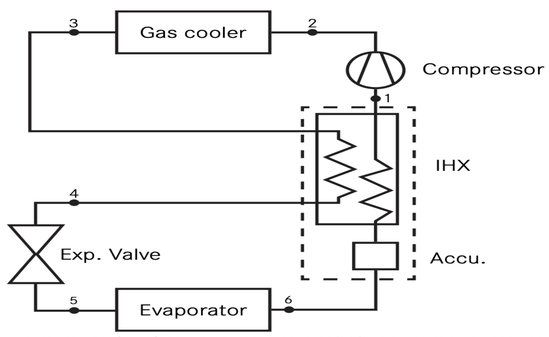
HOW DOES IT WORK

R-744 may be used in either a trans-critical or a subcritical system. Subcritical systems will not exceed the critical point (where gas and liquid are indistinguishable), while trans-critical systems will, and therefore must operate at greater pressures. Automobile systems will operate in the subcritical region, translating to lower material costs and requirements.. While pressures here will not require the same sort of strength as a trans-critical system, R744 systems require substantial improvements with respect to common automotive air conditioning parts. Changes will include the use of flexible steel hoses and steel compressor housings.

The compressor is the prime mover of the system, in which the refrigerant experiences an increase in pressure and temperature. Passing to a heat exchanger, the heat is exhausted to the ambient environment, and superheat is removed. A throttling device will meter the flow of refrigerant and drop the pressure, causing temperature to drop. The refrigerant will pass to heat exchanger and accumulate the undesired heat. Refrigerant returns to the compressor to repeat the cycle.

- Compressor
- Heat Exchanger ("Condenser" or "Evaporator")
- Throttling Device
- Heat Exchanger ("Condenser" or "Evaporator")

Note below the example cycle with an "IHX" or "internal heat exchanger" to produce a more efficient system. This system additionally includes an accumulator to store refrigerant.



Notice the work flow of the internal heat exchanger (IHX), using the relatively cool gas exiting the evaporator and accumulator to cool the hot refrigerant after it exits the gas cooler (condenser).

Sanden design for an automobile CO_2 refrigerant compressor. Note the timing belt connection; this must be affixed to an internal combustion engine.

MAKING THE CHANGE TO R-744, OUR FUTURE AUTOMOBILE REFRIGERANT

Many reasons to switch to this refrigerant:

- Naturally occurring CO_2 is safe to handle, and not flammable. It is desirable for use in conditions like the engine bay of a car, where hazardous materials and temperatures are present.
- Environmentally friendly, R-744 can be used without depleting the ozone layer and without making significant contributions to global warming.
- Widely embraced abroad, the United States has been slower to adopt R-744. However, the refrigerant is being introduced to the North American market.
- A few challenges do exist with respect to R-744 adoption, systems will operate at a much higher pressure than conventional auto AC's and will have a low critical temperature. This translates into greater manufacturing cost as the materials used will need to be much more resilient.
- Many current compressor designs are intended for use in internal combustion engines, and it is not easy to procure an electrically powered system.

WHAT ABOUT THE COMPETITION?

With no shortage of refrigerants, our available selection is enormous. Many refrigerants are available with relatively low GWP values, and similar usefulness to R-744.

R-1234yf is a popular refrigerant, with wide adoption in the US, in respectable vehicles like the Honda Accord. While R-1234yf does have a very low GWP (4), it is also very flammable, producing a robust flame and greater danger for the occupants. Note also that R-1234yf will not produce satisfactory heating effects when the ambient temperature reaches a low of about 23 Fahrenheit. This is not true of R-744 which will successfully heat even at very low ambient temperatures.

R-134a is a common auto refrigerant, and easily accessible in forms to include "quick refills" at national retailers. While R-134a represented a great improvement, its GWP of 1430 is not comparable with the relative harmlessness of R-744.

The Mercedes Benz S-Class sedan, an example of an early adopter of R-744, Mercedes felt that the industry's movement to R-1234yf was short-sighted. Citing the flammability and GWP of R-1234yf, MC engineers decided to move faster into the future and worked with Sanden to produce new components for their automotive AC.

KEY CONSUMERS AND INTERESTED GROUPS

- Consumers who are concerned with the environmental impact of their vehicle.
- Consumers who live in climates with long cold periods. These individuals will find that their R-744 systems operate as heaters very favorably compared with R-134a systems.
- Automotive manufacturers like Volkswagen and Mercedes have decided R-744 is worth the long-term investment and consider the material to be their refrigerant of the future.

The Volkswagen ID4, the first production car to use an R-744 heat pump system. This configuration is sold in Canada and Northern Europe.

JAPANESE ADOPTION OF R-744 AND MARKET GROWTH