CO₂ as refrigerant – status and prospects

Pega Hrnjak
pega@illinois.edu
Director ACRC,
Will Stoecker Res. Professor,
University of Illinois, Urbana-Champaign, USA
President, CTS
Creative Thermal Solutions, Inc.
CO₂ refrigeration systems perfectly fit in the moto of the congress

Towards healthy, sustainable and resilient buildings, settlements and cities with zero CO₂ emission

• Because it is the only refrigerant that is:
  − Nonflammable
  − Nontoxic (>4% should be avoided)
    − 0 ODP
    − 0 GWP

• Many people challenge efficiency and the cost
Extremely credible SAE AR CRPs concluded Technology evaluation framework

- Same outer sizes of HXs, air flow rate and test conditions
- Refrigerant-side free to be adjusted
- Capacity Q held equal to the baseline R134a - the only measure of difference was COP
- Project controlled by the Expert Team: 4 excellent engineers from major OEMs in charge of one system (refrigerant)
- Strict confidentiality motivated technology providing companies to supply the best components known
- Outer dimensions of equipment and generic descriptions revealed
- Results were released to the participants immediately and to the public one year after the final presentation

Almost entire industry participated
Summary: R134a vs. CO$_2$ in SAE MAC program: Identical capacity, same size HXs

CO$_2$ systems are not inferior, they are equal in performance.

The cost was the reason R1234yf was selected to replace R134a.
So, we have shown that CO$_2$ has

- Equal and sometimes even better performance
  - SAE CRP
- Very light and compact equipment
  - SAE CRP
- In some cases EQUAL costs!
  - CTS
  - Presentation at Atmosphere America, Atlanta, GA, June 2015
Measurements indicated some reasons for unexpectedly good performance.
Situation today

- Wide variety of applications
- Real commercialization with potential to become main option in some applications
In automotive systems

• Difficult restart, but Daimler officially announced CO$_2$ MAC system in production cars.

• R744.com:
  – “It has been quite a challenging project [...] for Daimler to get the R744 AC system launched in such [a] short period,” said Dr. Ralf Theurer, Project Leader R744 at Daimler AG.
  – The compressors’ cooling performance and function exceed conventional compressors with one fifth of capacity (31 cc).
  – “My target is to expand this technology and use the knowledge gained throughout the development to grow in a sustainable manner in the world market,” said Tsuguo Ito, president of Sanden Automotive Components Corporation.

• Currently almost 10,000 cars made by Daimler...
• Some other companies (VW, Audi, Porsche,...) follow...
In automotive systems

Electric vehicles:

• Heat pump systems based on CO\textsubscript{2} cycle show real advantage because R1234yf cannot provide Q and COP at low ambient conditions

• Real question: how important are electrical vehicles?
  - I do not think that is really a question in China government ordered min 8% of total production by 2020!

• Heat pump for electric car has an unique position: the only one HP that does not compete based on energy cost but is essential for function of the car increasing the range

• Heat pump extends the range for approximately 30%!! (function of the location and conditions)
In other heat pumps

Water heating:

• Residential:
  − Excellent success of Eco-cute in Japan, some other regions follow. After meteoric rise, being the first really commercialized CO$_2$ product with over 100,000 per year, mature situation.

• Commercial:
  − Various options implemented.
  − Expected to increase.
In air conditioning

• Residential:
  – Not much traction so far. Some of our very good results.
  – split system
  – R410A vs. CO₂

• Busses:
  – Long good history. Germany. Ongoing but not dominant.

• Trains:
  – Not much existing but significant interest lately: Europe and Asia
In refrigeration

**Industrial:**
- Slower than expected.
- Both in low stage and as secondary coolant options.
- Not many transcritical.

**Transportation:**
- Carrier’s CO$_2$ container system commercially available.

The largest CO$_2$ industrial project in the world completed in January 2017 at a lettuce plant in the Netherlands, with a $Q = 3.36$ MW.
In commercial refrigeration

Supermarkets:

- **Great successes.** Thousand of transcritical systems in Europe, significant numbers elsewhere
- Excellent example how ingenuity with consecutive improvements bring success: booster, precooling air to gas cooler, ejectors,...

Light commercial:

- Mostly driven by Coca Cola, McD, et al.
- CTS system, acknowledged by the manufacturer:
  
  equal performance and equal cost as R134a
  
  Manufactured in 100,000s

Recent challenges with pressure to expand allowable HC charge, but...
Massive Fire At London High-Rise Started In A Refrigerator, Police Say

June 23, 2017 · 8:19 AM ET

London high-rise fire caused by faulty freezer; manslaughter charges being considered | Fox News

"We now have expert evidence that the fire was not started deliberately — the fire started in a fridge-freezer — the make and model is a Hotpoint FF175BP," Detective
So, current situation shows wide range of applications

• Interestingly, successful applications are not necessarily in the areas where thermodynamic and thermophysical properties indicate the greatest comparative advantages (efficiency) like at low temperatures above triple point (-50 to -10°C)
What can we expect in years ahead

• Significant improvements in CO$_2$ technologies.
• Improvements in systems, but more importantly reliability and cost reduction coming from applications that provide mass production:
  – Primarily automotive
  – HPWH
  – Commercial
• That technology will transfer to other applications
• Even greater support form public and government
• Greater penetration of CO$_2$.
Efficiency increase through improvement of expansion process

Expansion devices

• Further increase in using ejectors:
  – More integration
  – Expiration of certain patents will open more opportunities

• Other simple devices

• More work on expanders
  – Nevertheless, I expect to see more applications with ejectors

Simplicity for cost reduction

Systems:

• Further expansion of transcritical systems

• Two refrigerant cascades will migrate to transcritical, very likely multistage systems

• One refrigerant, one lubricant, if any.
Scenarios for the future

• Green, ecological leaning will strengthen
• Every new wave of refrigerants lasted shorter, due to initially unknown properties. Current way may not be different.
• Some flammability related accidents are very likely to happen.
• CO$_2$ is the only intrinsically safe option and will be even more attractive at that point.
Pressure on efficiency (related to CO₂ generation) will change

- Energy is increasingly produced CO₂ free (without fossil fuel, using renewables, nuclear, ...)

U.S. 2014 Electricity Generation By Type

1/3 non-fossil fuel
In USA

In France

In CA this spring 34% solar + wind
Less than 10% fossil fuel

Denmark, Sweden, Germany: 40% wind energy and growing,
China is the leader in facilities for wind produced electricity
That affect calculation of LCCP the most accepted measure of CO$_2$ emission of our systems traces processes where CO$_2$ is released in atmosphere.
So LCCP will then look like:

(Just an illustration)
To conclude

• Even stronger days for CO$_2$ are ahead.

• There will be many opportunities for young engineers to present their knowledge and creativity by improving every aspect of CO$_2$ systems, related technologies and components.