



Fundamentals of Refrigeration

Refrigerants



What you will Learn in this Lesson

- Refrigerant types
- Properties
- Standard 34
- Ozone depletion and Montreal Protocol
- Climate change
- Current policy action
- Refrigerants of the future

Refrigerant Types

- Natural refrigerants
- Hydrocarbons
- CFCs
- HCFCs
- HFCs

Natural Refrigerants

- Ammonia (NH_3) R-717
 - Efficient
 - B2 classification
 - Industrial applications
- Water R-718
 - Absorption chillers
- Carbon dioxide (CO_2) R-744
 - Traditionally inefficient
 - Low critical point

Hydrocarbons

- Propane R-290
 - Efficient
 - ODP=0
 - GWP= nil
 - Classified as A3
 - Flammable
- Isobutane R600a
 - Efficient
 - ODP=0
 - GWP= nil
 - Classified as A3
 - Flammable

Chlorofluorocarbons - CFCs

- Examples
 - R-11, R-12, R-113 and R-114
- Safe and efficient
- Contain chlorine which depletes ozone
- R-11 and R-12
 - ODP = 1.0
- Phased out in 1995 by Montreal Protocol

Hydrochlorofluorocarbons - HCFCs

- Examples
 - R-22, R-123
- Efficient
- R-123 classified as 1B
 - Higher toxicity
- Contain some chlorine which depletes ozone
 - R-22 ODP = 0.05
 - R-123 ODP = 0.02
- R-22 phased out in USA in 2010
- R-123 will be phased out starting in 2020 (new equipment)

Hydrofluorocarbons - HFCs

- Examples
 - R-134a, R-410A, R-407C
- Safe and efficient
- Contain no chlorine
- ODP = 0
- Green house gases
 - e.g. R-404a GWP = 4900

Refrigerant Properties

- Many properties are required to make a good refrigerant
- Safety and efficiency often discussed
- Efficiency often abused

Safety

- Toxicity
 - Acute toxicity
 - Chronic toxicity
 - Threshold limit value (TLV)
- Flammability
 - Lower flammability limit (LFL)
 - Heat of combustion (HOC)
- ASHRAE Standard 34
 - New 2AL and @AH classification

	Lower Toxicity	Higher Toxicity
Higher Flammability	A3	B3
Lower Flammability	A2 A2L*	B2 B2L*
No Flame Propagation	A1	B1

* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤ 10 cm/s (3.9 in/s)

Efficiency

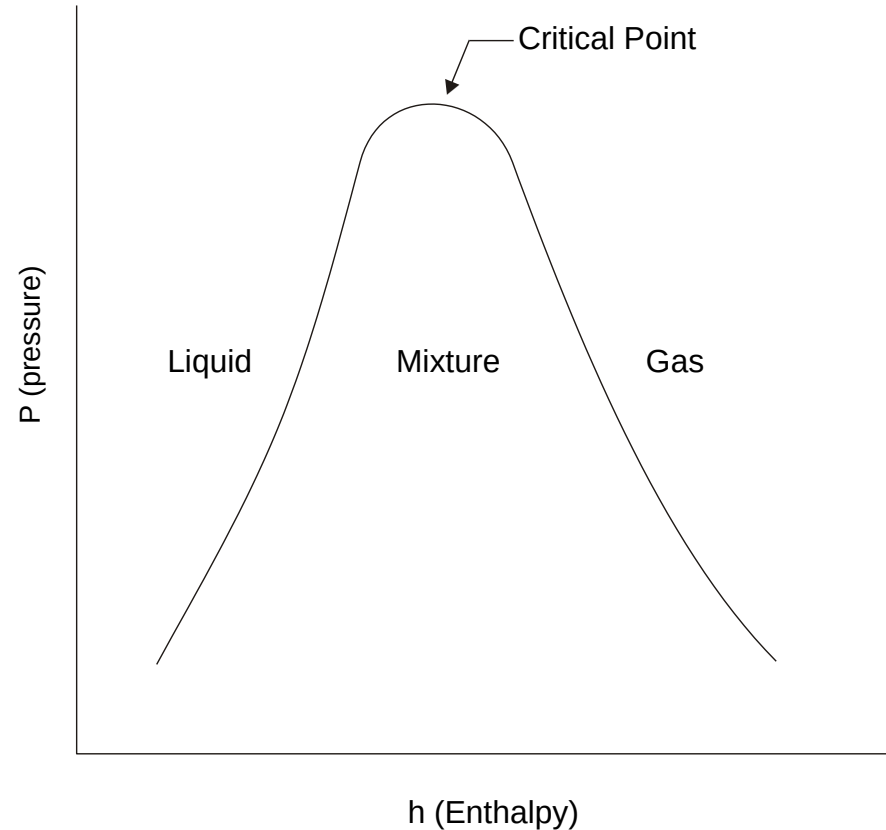
- Carnot efficiency is best possible
 - Doesn't even include refrigerant properties
- Efficiency is property of system not refrigerant!
- Systems must be designed to take advantage of refrigerants
 - Subcooling
 - Refrigerant economizers
- No generic “system model” will show all refrigerants fairly

Heat Transfer Properties

- Refrigerant can be efficient But have poor heat transfer properties
 - Ex. R-134a is better than R-123
- Heat transfer based on
 - Viscosity
 - Specific heat
 - Thermal conductance
- Good heat transfer means:
 - Closer approaches
 - Lower compressor lift
 - Better system performance

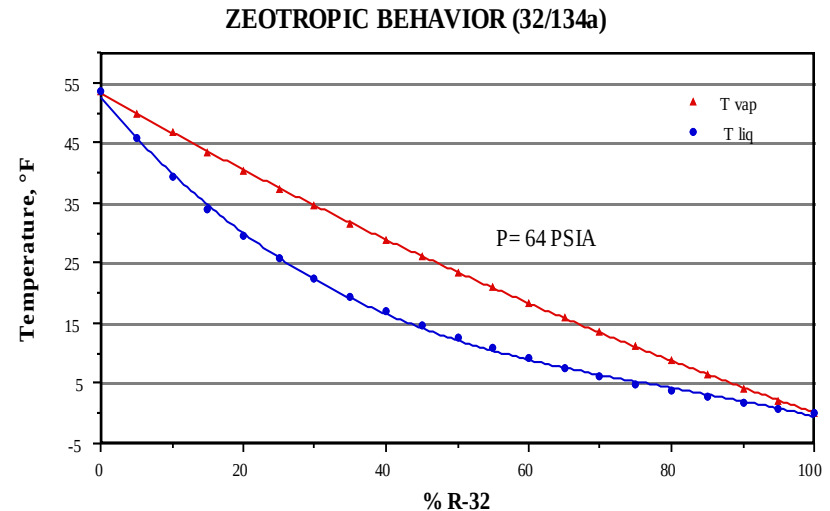
Critical Point

- Point where liquid and vapor properties meet and become indistinguishable
- No condensation possible above critical point
- Below but near critical point
 - High volume capacity
 - Low efficiency
- R-410A



Glide

- Temperature difference Between beginning and end of phase change process
- Zeotropic refrigerants tend to have some amount of glide
- Large glides cannot be used with flooded evaporators
 - Ex. R-407C



Other Refrigerant Properties

- Acoustic velocity
 - “Speed limit” on transport design
- Boiling point
 - Indicator of temperature level refrigerant can be used at
- Freezing point
 - Refrigerant cannot be used below freeze point
- Materials compatibility
- Lubricants
- ODP and GWP
 - Discussed later

Refrigerant Chemistry

- Only a small number of chemicals can meet refrigerant requirements
- Fluorocarbons are among the best
- Many other groups have been investigated but they have been:
 - Toxic
 - Flammable
 - Poor performers

Fluorocarbons

- CFCs, HCFCs and HFCs
- Limited combinations
 - Adding chlorine or bromine increases ODP
 - Adding fluorine increases GWP
 - Adding hydrogen increases flammability and lowers atmospheric lifetime

Blends

- Mixture of two or more refrigerants
- Azeotropes
 - Components behave as one refrigerant
- Zeotropes
 - Change saturation temperature as it boils (glide)

Refrigerants and Systems

- Best performance is achieved when refrigeration system and refrigerant are matched
- No such thing as a perfect refrigeration system that works well with every refrigerant
- Most commercial systems are;
 - Absorption (water is a refrigerant)
 - Vapor compression

Compressors

- Compressor provides “lift”
 - Increase in enthalpy (Pressure and Temperature)
- Operating conditions set lift
 - Air cooled higher than water cooled
 - Low temperature refrigeration higher than A/C
- Refrigerant flow rate = capacity

Compressors

- Positive displacement Compressors tend to be;
 - High lift
 - Low volume flowrate
- Centrifugal compressors tend to be;
 - Low lift
 - High volume flowrate

Refrigerants And Compressors

- R-11 And R-123 need high volume flow rates (17cfm/ton)
 - Require centrifugal compressors
- R-410A, R-22, R-407C have lower flow rates
 - Can use positive displacement compressors
- R-134a works well with screw and centrifugal
 - Okay with other positive displacement compressors

Refrigerants And Heat Exchangers

- Evaporators and condensers are heat exchangers
- Heat transfer proportional to surface area (number of tubes) and ΔT
- Good heat transfer allows;
 - Closer approaches
 - Lower lift and better performance
 - Or less copper and better price
- Refrigerants with glides (R-407C) don't work well in flooded evaporators

Refrigerant Transport Properties

- Pressure drops occur in connecting piping and system components
- Pressure drops = temperature changes
- Adversely effect heat exchanger approaches
- Some refrigerants are worse than others
 - Ex. R-134a better than R-123

Refrigeration System Model

- Model chiller at ARI conditions
- Carnot efficiency is 0.323 kW/ton
- Ideal cycle
 - Ideal heat transfer
 - Isentropic compression (100% efficient)
- R-123 = 0.393 kW/ton
- R-134a = 0.415 kW/ton
- Ideal cycle cannot be built!

Refrigeration System Model

- Real world model
 - 2 F approaches For R-134a
 - 3 F approaches For R-123
 - 83% efficient compressor for R-134a
 - 82% efficient compressor for R-123
- R-123 = 0.546 kW/ton
- R-134a = 0.541 kW/ton

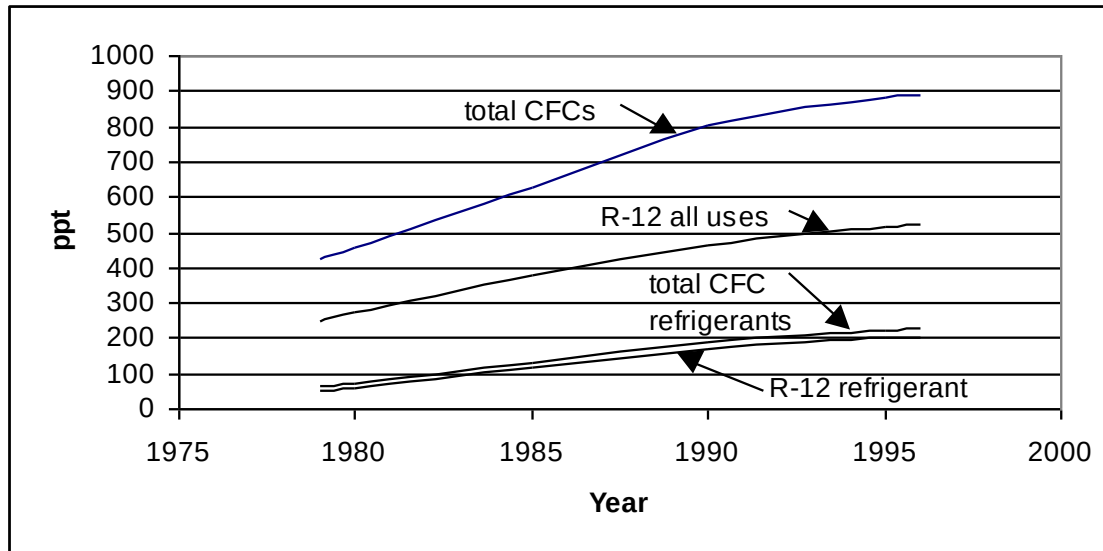
Refrigeration System Model

- Real world model with non-condensable
 - Same as before
 - Additional 2 F condensing temperature for non-condensable
- R-123 = 0.567 kW/ton
- R-134a = 0.541 kW/ton
- Performance is sensitive to non-condensable

Stratospheric Ozone Depletion

- Ozone protects life from ultraviolet radiation
- 1974 Molina And Rowland identified CFCs as source of chlorine that destroys ozone layer
- 1985 results published showing thinning of ozone layer (Ozone Hole) over Antarctica
- Other ozone depleting substances include
 - Halons, carbon tetrachloride, methyl chloroform, HBFCs and methyl bromide
- 1987 Montreal Protocol Ratified

CFCs And Ozone Depletion



- 27% of CFCs in atmosphere from refrigeration
- 83% Of HCFCs in atmosphere from refrigeration
- Refrigerant responsible for 28% anthropogenic (manmade) ozone depletion
- Refrigerants key to protecting the ozone

Montreal Protocol Annex 1 Countries

- 1987 50% reduction in CFC production by 2000
- 1990 100% CFC phase out by 2000
- 1992 CFC phase out advanced to 1996, HCFC capped at 1989 levels plus 3.1% of CFC production
 - 65% of cap in 2004
 - 35% of cap in 2010
 - 10% of cap in 2015
 - 0.5% of cap in 2020
- 1995 CFC portion of cap lowered to 2.8%
- 1997 HCFC consumption from 2020 to 2030 only for service

Montreal Protocol Annex 2 Countries

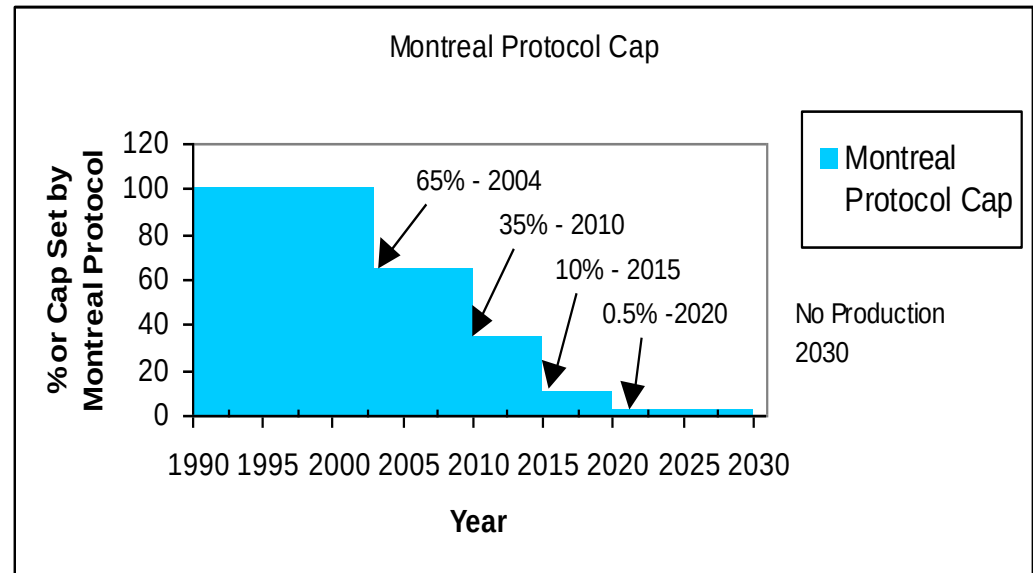
- Annex 2 are developing countries
- 1999 CFCs capped at 1995-97 average
 - Phased out by 2010
- 2016 HCFCs capped at 2015 levels and phased out by 2040

EPA And Montreal Protocol

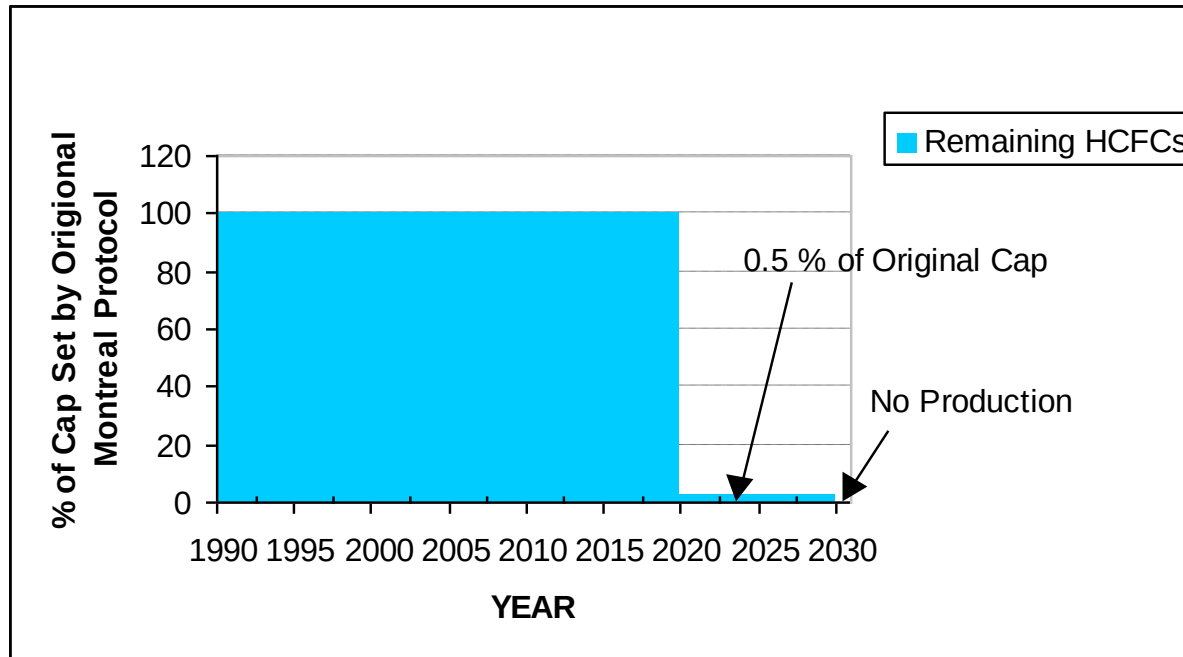
- Montreal Protocol enforced by EPA section 604 of Clean Air Act
- CFCs phased out in 1996 as required
- Only source of R-11 and R-12 is reclamation

EPA And HCFCs

- Montreal Protocol is based on ODP weighted HCFC average
- EPA is phasing HCFCs with higher ODP potential out faster than listed by Montreal Protocol to ensure USA is in compliance

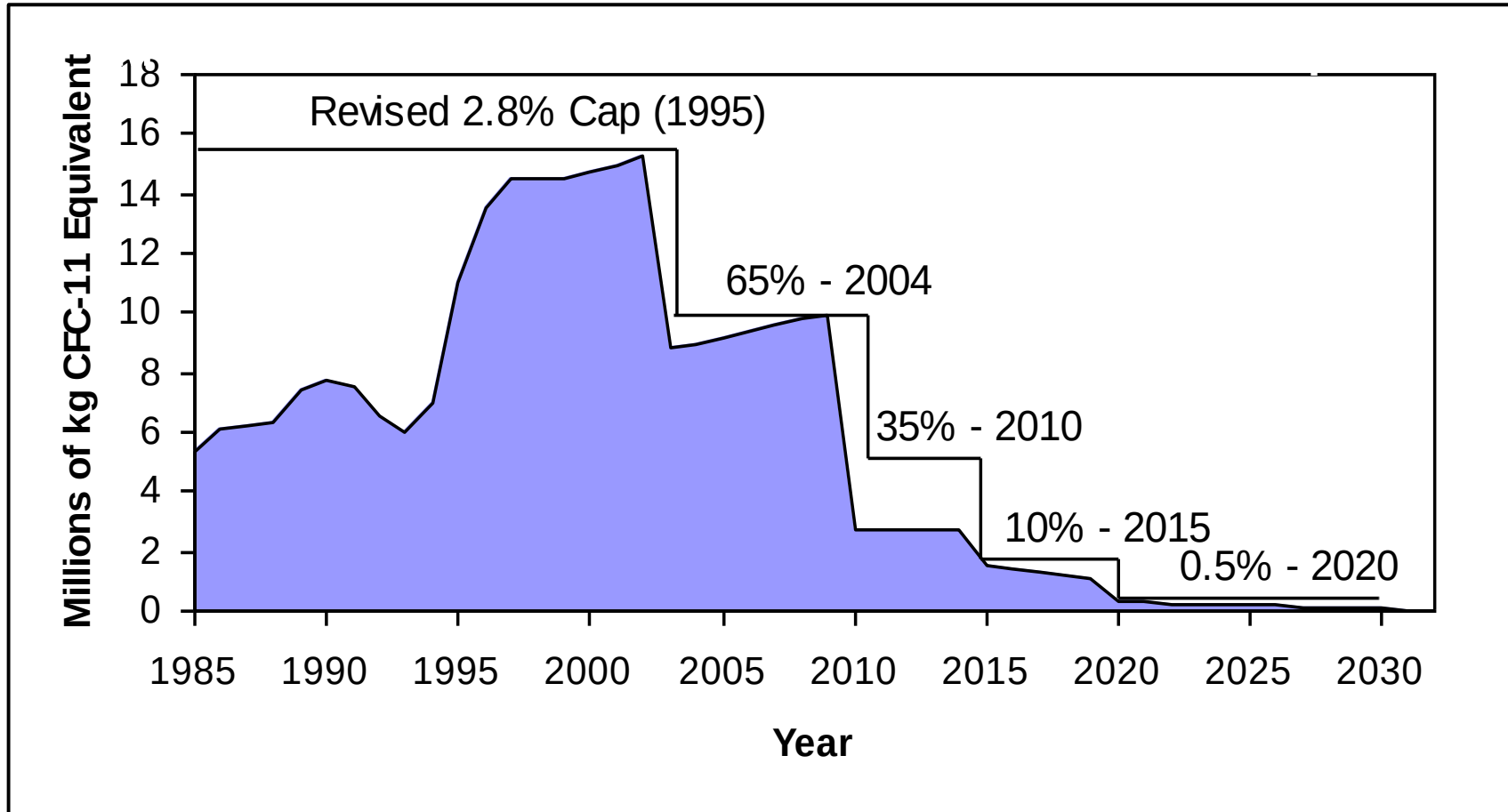


Remaining HCFC Phaseout



- No use in new equipment after 2020
- 0.5% production for service only to 2030
- Will allow USA to meet Montreal Protocol

Montreal Protocol Phase Out



Montreal Protocol Results

- Considered most successful international treaty ever
 - Sound science
 - Universal ratification
 - Step down approach allowed transition
 - Different time table for developing countries
- UNEP estimates global ozone levels are expected to return to 1980s levels by 2050

Status as of Today

- HFCs are main refrigerants
 - R-407c, R-410A, R-134a, R-404a
- CFC stock piles are an environmental issue that must be destroyed
 - Still large number of existing chillers with R-11 (CFC)
 - Governments taking action to phase out and destroy CFCs
 - Canada

Climate Change (Global Warming)

- Earth is warmed by incoming radiation from sun
- Atmosphere absorbs 2/3
- 1/3 reflected back by clouds, particles and surface
- Certain gases in atmosphere can “trap” reflected radiation
 - Known as greenhouse gases
- Some trapping is good - too much causes Global Warming

Climate Change (Global Warming)

- 1995 IPCC reported to UN that:
 - “The balance of evidence suggests a discernible human influence on global climate”
- Over 2000 scientists reviewed this paper
- Evidence suggests
 - Global average temperature could rise by 1.8 to 6.3 F by 2100
 - Sea levels rise by 6 to 37”
- The problem is real, only the severity is in question

Greenhouse Gases

- Methane
- Nitrous Oxide (NO_2)
- CFCs and HCFCs
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)
- Carbon dioxide (CO_2)
- HFCs

Greenhouse Gases

- Measured in Global Warming potential (GWP)
 - Based on carbon dioxide (most abundant greenhouse gas)
 - Effect a similar mass of carbon dioxide would have over a 100 year period
- CO₂ level 150 years ago was 270 ppm
 - Today level is 370 ppm
- Even if Kyoto Protocol is adopted, the level will still double by 2050, triple by 2100 and quadruple by 2150
- CO₂ mainly comes from burning fossil fuels for energy

Refrigerants And Climate Change

- CFCs, HCFCs and HFCs all greenhouse gases
- Direct effect
 - Refrigerant released to atmosphere
 - Only 3-4% of anthropogenic greenhouse gases
- Indirect effect
 - CO₂ emitted providing energy to operate refrigeration
- Buildings represent 40% of all energy consumed in North America

Climate Change Legislation (USA)

- Most legislation focused on energy policy
 - Refrigerant (HFC) phase out or down minor part
 - Waxman – Markey Bill (stalled)
- Change in government last November stopped a lot of activity in energy area
- EPA decided that CO₂ is an environmental issue and that they can regulate it

Climate Change Legislation (USA)

- NGOs pushing at state level for HFC phase out and strong energy reductions
- Energy continues to be the top focus
- ASHRAE and others push a balanced solution
 - If phasing out HFCs raises energy usage then we have gone backwards

Kyoto Protocol

- Everyone signed but USA
- Few ratified
- Not very effective – Ends 2012
- Countries made commitments to reduce CO₂ emissions from a base line
 - Details left up to individual countries
 - USA identified a basket of greenhouse gases including HFCs that would be “phased down” not out
 - Never signed on so it never happened

Copenhagen Accord

- USA heavily involved
- Extension of Kyoto Protocol
- Non binding
- Early days
- Current country targets include;
 - USA 17% reduction
 - Canada 17%
 - China 40-45%
 - India 20-25%

Current status

- No formal phase out for HFCs in the USA
- Everyone expects one
- Europe has HFC phase out for MACs starting this year
 - CO₂ systems for cars
 - HFOs for cars

Next Generation Refrigerants

- Will be more reactive because they need to break down in the environment
- They will react with materials, atmosphere and oil
- If you could design a chiller today for a refrigerant that does not exist yet you would:
 - Try to avoid oil
 - Limit the charge
 - Ultra low leakage rate
 - High possible energy efficiency (low TEWI)

End of Lesson

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