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Experimental and Modeling Improvements to a Co-Fluid Cycle Utilizing Ionic Liquids and Carbon Dioxide

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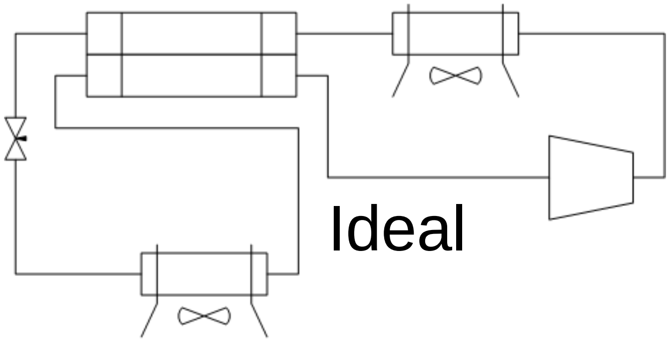
Presentation outline

- Overview of the co-fluid cycle and thermodynamics of the co-fluid pair
- Modeling for ionic fluid selection
- Experimental facilities for systems testing
- Exploration trends in data
- Performance non-idealities and areas to focus for improved performance
- Conclusions

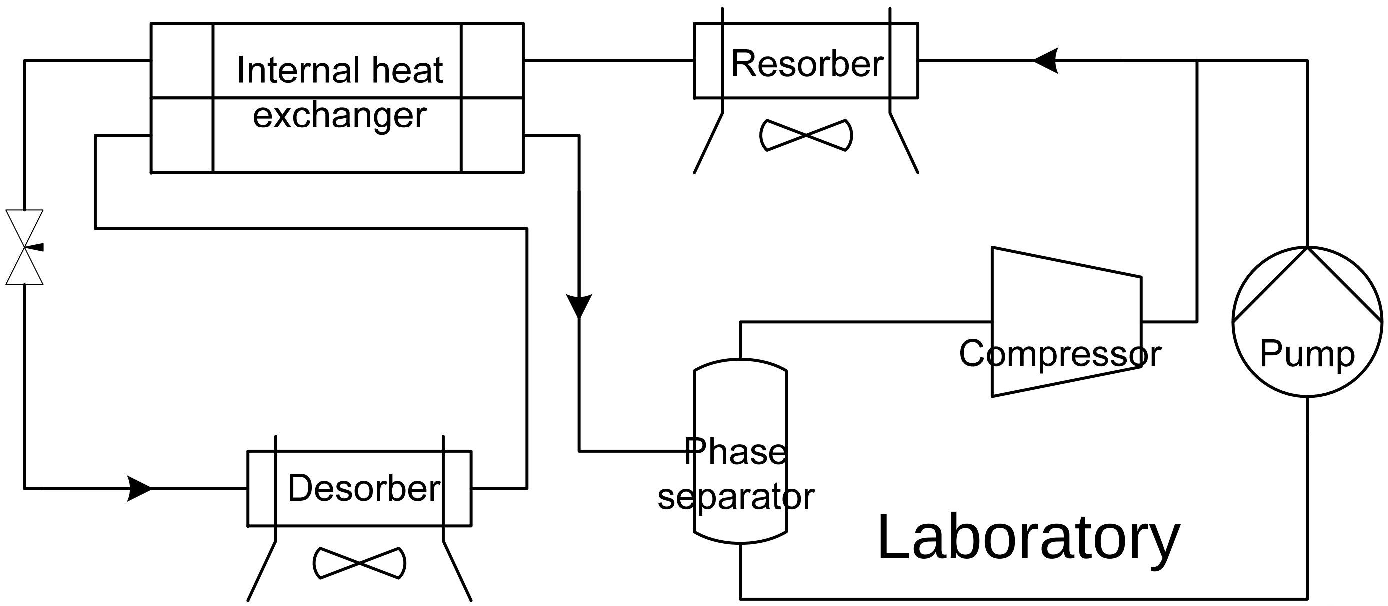
What is a co-fluid cycle?

- Same basic concept as a traditional vapor-compression cycle, but takes advantage of some thermodynamics of absorption cycles
- A non-volatile liquid is utilized to lower the pressure at which the volatile refrigerant changes phase
- Spauschus et al (1999) demonstrated possibility of using such a cycle to lower the operating pressures of carbon dioxide to the levels of common automotive refrigerants
  - » Cofluids: Neopentylglycol diacetate, diisobutyl adipate, N-methyl-2 pyrrolidone
- Others refer to such cycles as "heat pump cycles with solution circuits" or "chemically assisted vapor compression cycles"

Co-fluid cycle components



- Laboratory system utilized pump in parallel with compressor
- Less efficient, but robust and allowed independent control of parameters



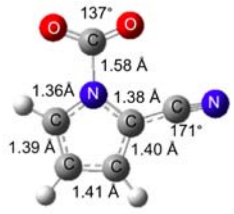
Co-fluid pairs

- Carbon dioxide utilized as refrigerant due to its well known strengths:
  - » Safe (non-flammable with very low toxicity)
  - » Inexpensive
  - » Good transport properties
- Primary weakness stems from low critical temperature and high critical pressure: co-fluid cycle can mitigate
- Previous co-fluid pairs involved chemicals such as acetone

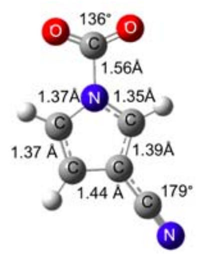
Ionic liquids

- Ionic liquids are salts which are liquid around room temperature
- Cations and anions can be individually selected organic ions
  - » Anions have strong effect on absorption
  - » Cations have strong effect on viscosity
- Ionic liquids are good candidates for co-fluid because:
  - » Stay liquid at relevant temperatures
  - » Can be selected to absorb/desorb at relevant temperatures and pressures
  - » Transport properties can be adjusted

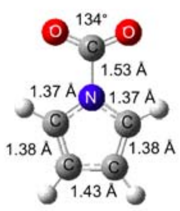
Gaussian *G3* calculations



-49 kJ mol^{-1}

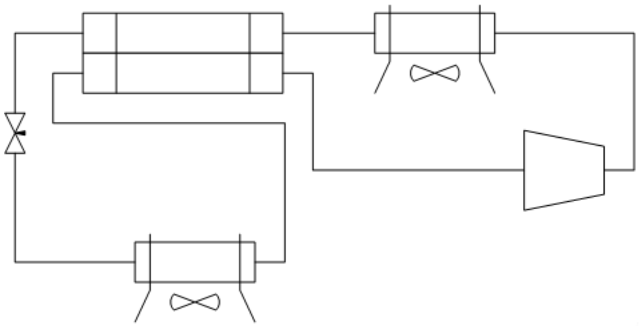


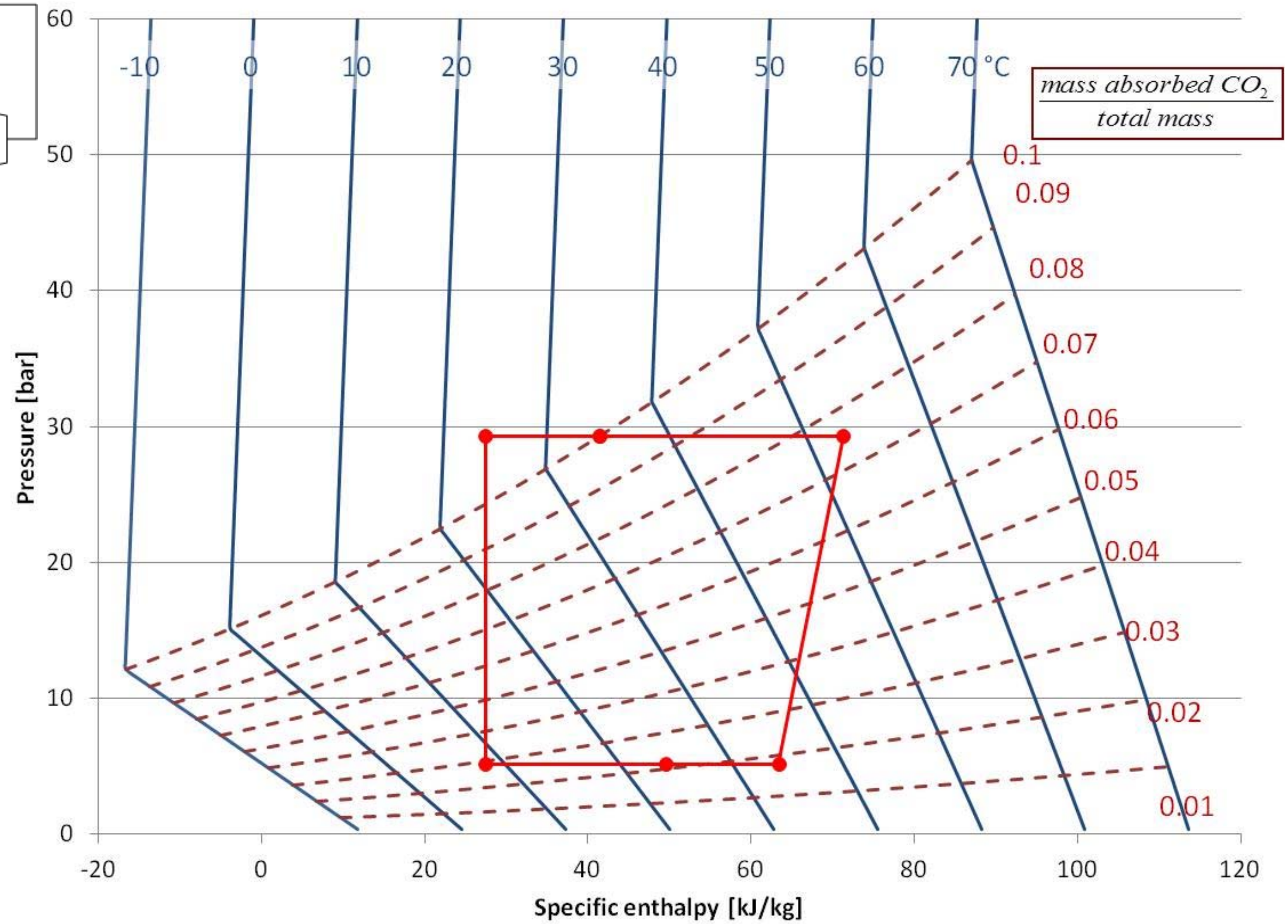
-70 kJ mol^{-1}



-109 kJ mol^{-1}

Co-fluid cycle on a p-h diagram



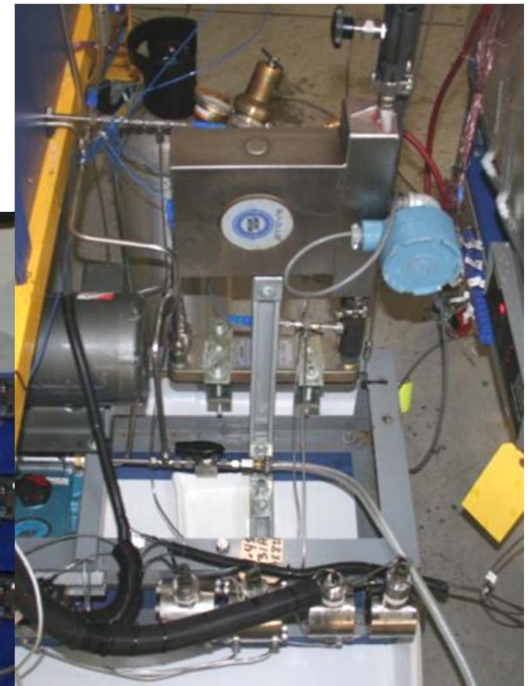


Modeling for ionic fluid selection

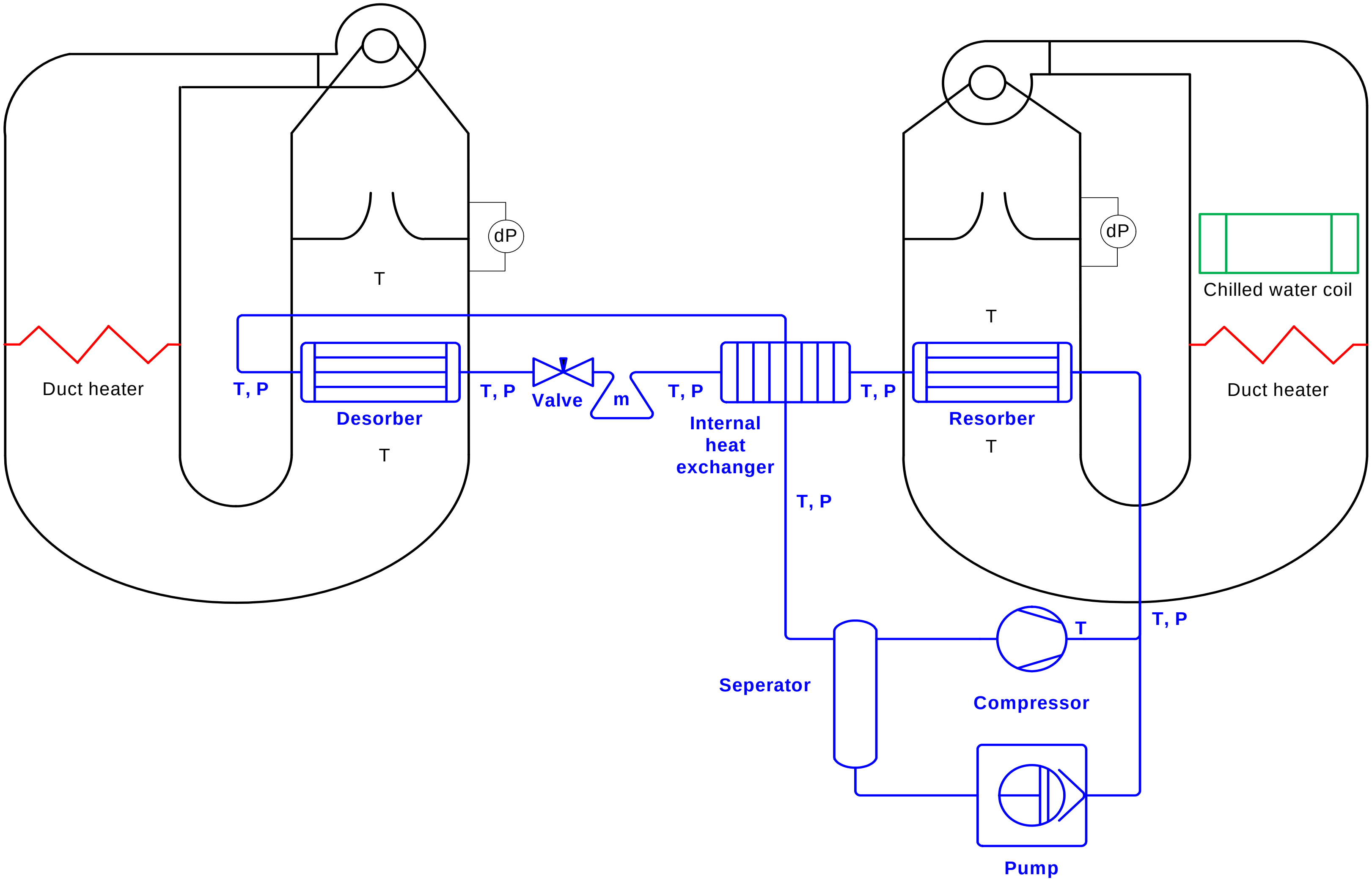
- Main goal of selecting ionic liquids for co-fluid cycles is to have good performance: high COP and cooling capacity
- Cycle model used was first presented by Mozurkewich et al (2002)
  - » Uses thermodynamic mixture properties
  - » Allows non –ideal heat exchanger effectiveness
  - » Calculates based on isentropic wet compression
    - – Later expanded to include independent compression and pumping
  - » Isenthalpic expansion
- Primary model weaknesses
  - » Does not account for non-equilibrium effects
  - » Viscous effects are neglected
- Model is useful primarily for screening studies to identify suitable ionic fluids

Laboratory facility

- Due to time constraints, facility constructed with off-the-shelf components



Laboratory facility



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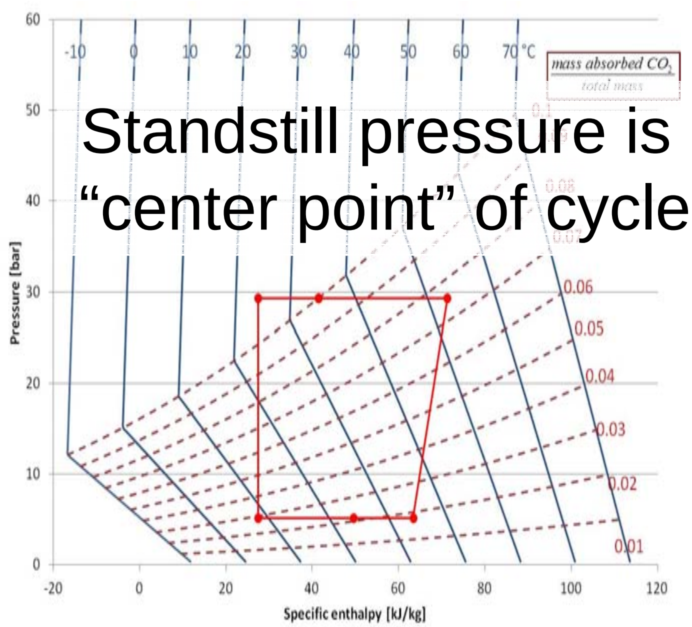
Experimental trends

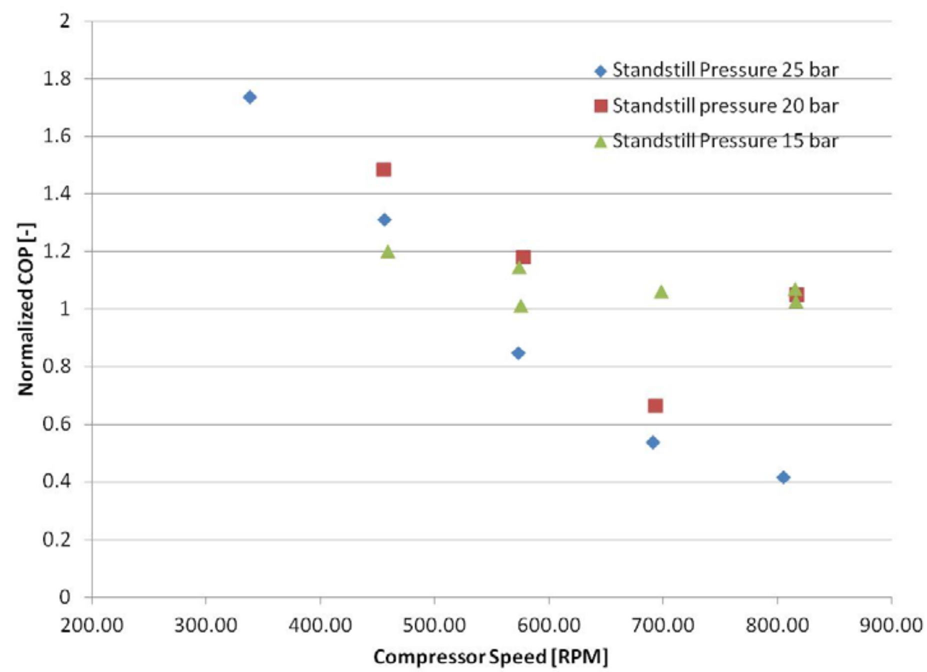
- Due to a few limitations, which will be discussed later, COP was far below from modeled values
  - » COP will be compared to a baseline with a COP of 37% and a capacity of 566W
- These limitations relate primarily to
  - » Not achieving thermodynamic equilibrium at inlet/exit of each component
  - » Compressor not capable of handling large quantities of liquid
  - » Low efficiencies of compressor and pump, as well as motor and VFD, due to low speed operation
  - » Improper tube sizing in heat exchangers related to viscous effects

Effect of relative charge of carbon dioxide to ionic liquid

- Standstill pressure at room temperature is a function of relative charge of IL and CO_2
- Optimal charge ratio necessary to maximize efficiency

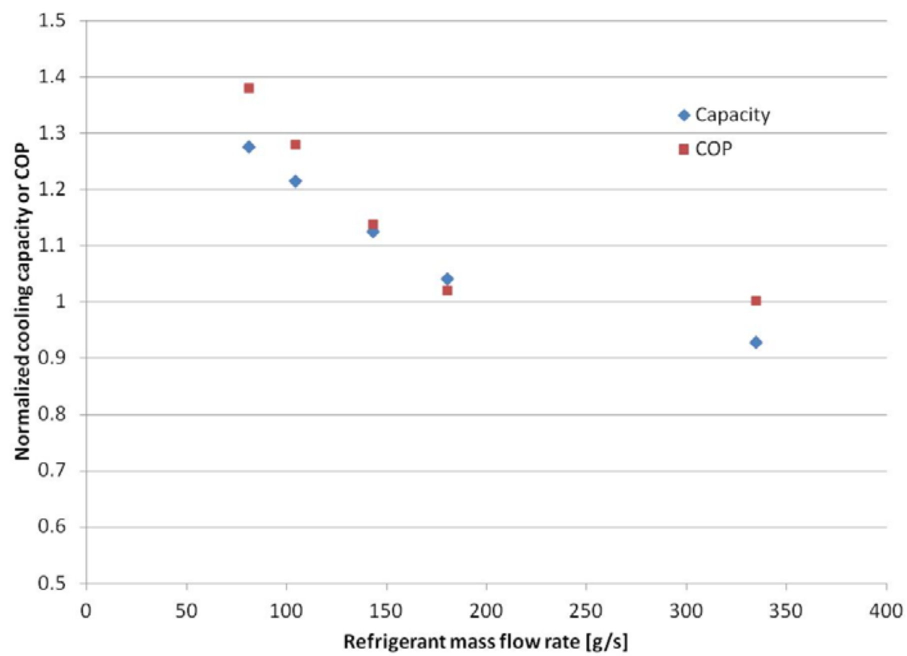


Standstill pressure is "center point" of cycle



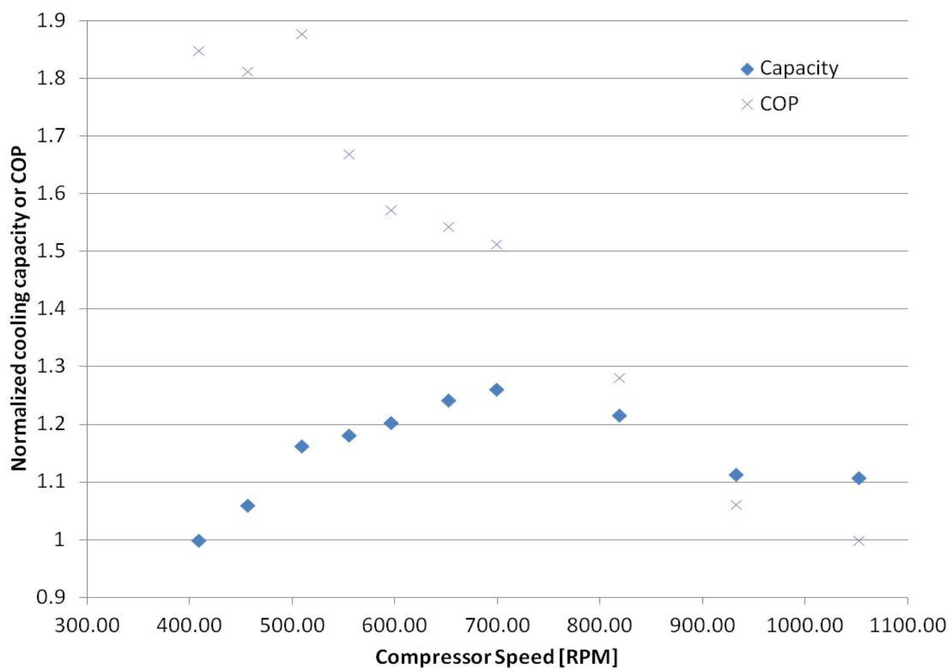
Effect of expansion valve opening

- Expansion valve opening is not directly measured; mass flow serves as a surrogate
- Opening the valve increases flow but decreases the pressure difference between the high and low side
- Similar to other systems with very high glide fluids, high side pressure is very important



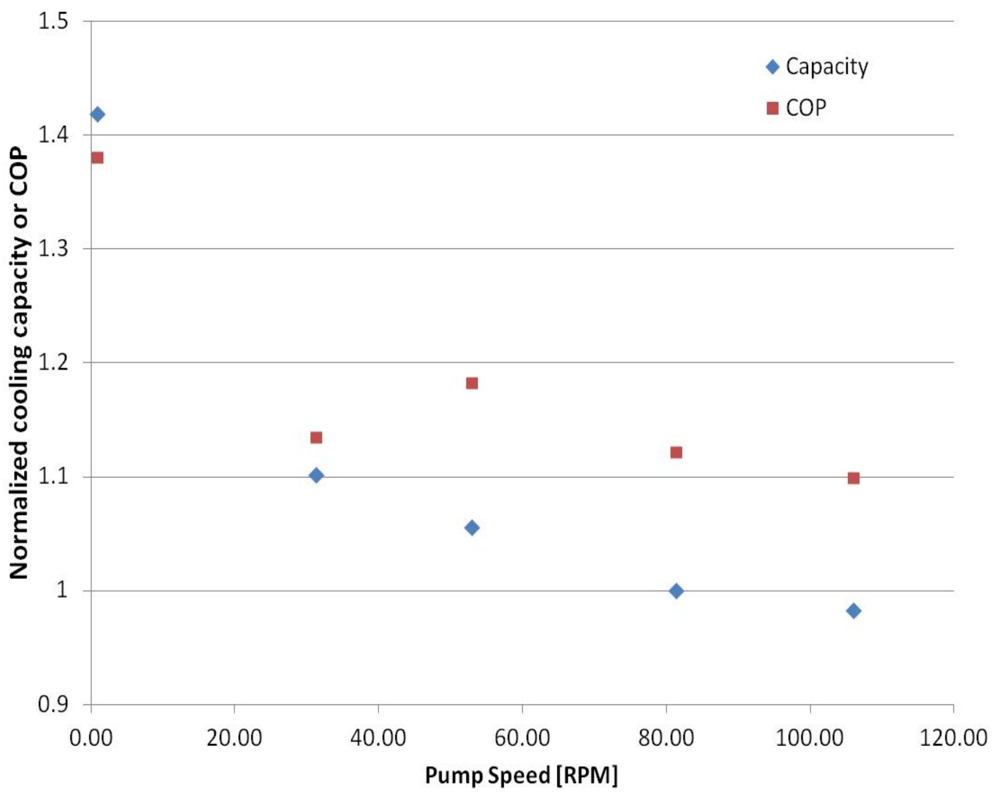
Effect of compressor speed

- Compressor effects system by creating pressure difference and {refrigerant} mass flow
- Very small, open shaft compressors were not available so compressor utilized was oversized
  - » Reducing speed increased COP
- Capacity increased due to increasing mass flow, then decreased due to shift in relative flow rates
  - » Little capacity from pure CO_2 at high side pressures <30 bar



Effect of pump speed

- Pump speed controlled the relative flow rate of IL to CO_2
- Since IL is non-volatile it does not directly contribute to cooling
- Higher fractions of IL lead to warmer temperatures after the expansion process



Key performance non idealities

- Allowing sufficient time/space to achieve equilibrium
  - » Exit of expansion valve did not get sufficiently cold prior to entering desorber
  - » Speed mass diffusion process, allow more time, or create greater liquid-vapor area
- Achieve wet compression
  - » Models showed that wet compression is necessary to achieve good performance and to have low discharge temperatures
- Design heat exchangers for fluid
  - » Due to high glide and high viscosity compared to other refrigerants, dramatically different designs must be built to achieve good performance

Conclusions

- Ionic fluid based co-fluid cycles allow carbon dioxide to be utilized at much lower pressures for air conditioning applications
- Ionic fluid screening from models is possible
- Performance improved by
  - » Proper relative charges of co-fluids
  - » Proper expansion valve setting
  - » Proper sizing of heat exchangers compared to compressor
  - » Having “wet” compression
  - » Designing components for unique properties of ionic-liquid co-fluid pairs

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