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ONLINE

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Energy Savings in Commercial Air Conditioning by Use of a Low-charge Ammonia Chiller

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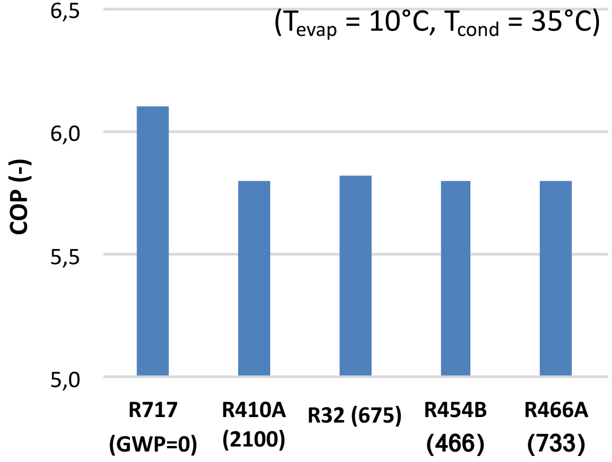
Outline

- Objective: Demonstrate opportunity for significant improvement in medium capacity ammonia chiller by simple addition of ejector for evaporator overfeed
- Background:
  - Energy efficiency of ammonia compared to other refrigerants
  - Low-charge ammonia chiller
  - Ammonia chiller improvement: Evaporator overfeed, ejector technology, evaporator overfeed with ejectors
- Evaluation of effect of ejector overfeed on a brazed plate evaporator
  - Evaporator performance improvement, chiller capacity and COP improvement

Motivation and Objectives

- Ammonia (NH_3, R717) is one of the most promising refrigerants of the future due to its high efficiency and favorable environmental friendliness
- Due to toxicity concerns, ammonia is limited in how widely it can be applied, leading to low-charge and/or use of indirect (chiller) or cascade systems, all of which decrease efficiency
  - E.g. Ammonia has yet to find wide acceptance in domestic AC despite significant potential for improved efficiency and GWP
- Efficiency of indirect or cascade systems, often using brazed plate evaporators, can be improved by overfeeding the evaporator, as will be demonstrated in this study

Simulated COP of refrigerants under air-conditioning conditions (T_{evap} = 10°C, T_{cond} = 35°C)



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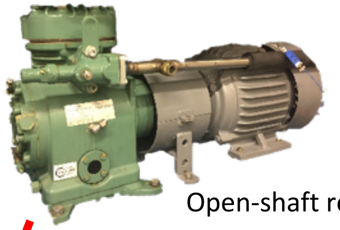
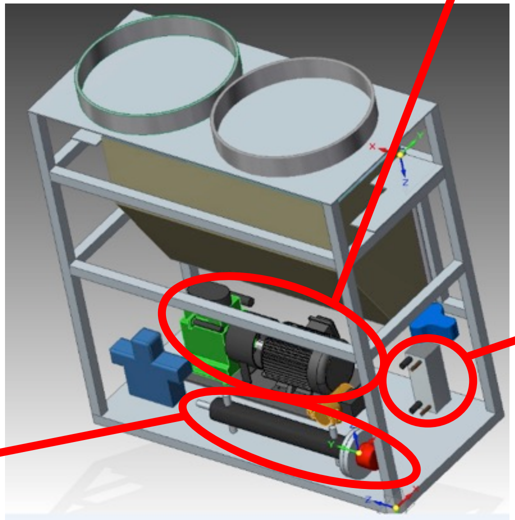
CTS Low-charge Ammonia Chiller

- 20 kW capacity at AC conditions
- < 800 g total system charge (> 25 kW per kg-NH_3)
- Low charge achieved with small line sizes, microchannel condenser, and DX brazed-plate evaporator



Open-shaft reciprocating compressor



Electronic expansion valve and nickel-brazed plate evaporator

Custom-designed microchannel condenser for significant charge reduction

Glycol pump and heater to simulate load for evaporator

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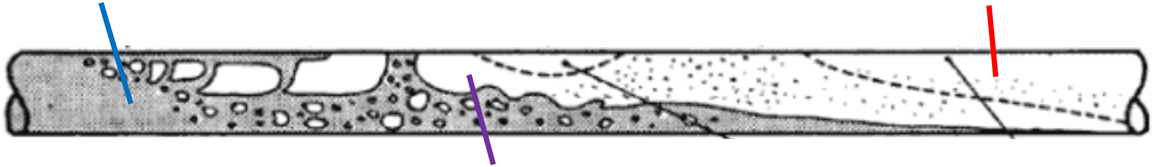
Ammonia Heat Transfer in Evaporator

- Ammonia heat transfer coefficient (HTC) in evaporator varies significantly as amount of liquid vs. vapor (quality) changes throughout



- High quality and superheated region at end of evaporator has very low HTC because of absence of liquid
- Additionally, superheated increases NH_3 temperature, reducing ΔT between NH_3 and heat source

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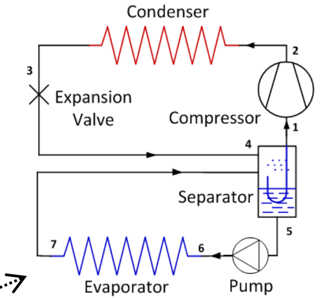
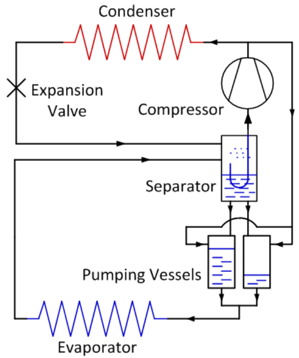
Evaporator Overfeed Cycles

- Cycles in which more liquid is fed to evaporator than evaporate, resulting in a two-phase outlet
- Liquid overfeed results in:
  - Reduced or elimination of dryout in tube (most significant benefit)
    - Significantly improves HTC
    - Increases DT between NH3 and heat source throughout evaporator
  - Reduced relative pressure drop
  - Potentially improved refrigerant distribution
  - Increased charge
- Options for pumping liquid through evaporator:
  - Motor-driven pump
  - High-pressure vapor
  - Gravity
  - **Ejector**





Pumped overfeed is common in large ammonia plants but not practical when using ammonia in small- or medium-scale applications.

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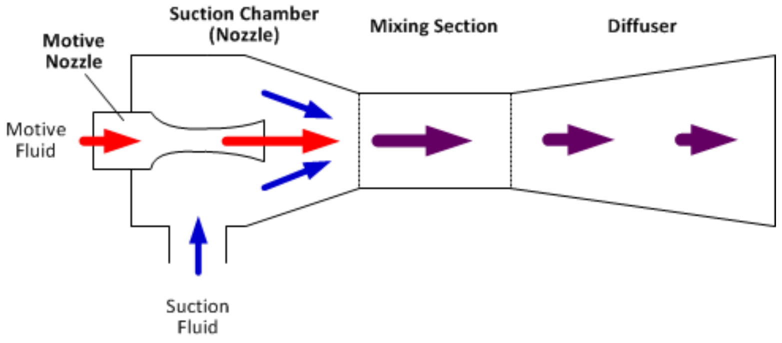
Ejector Technology

- Ejectors are work recovery devices that use the expansion of a high-pressure stream to provide pumping and pressure lift to a lower-pressure stream
  - Advantages: Simple construction and operation (no moving parts), low cost, ability to function effectively with two-phase flow
  - Disadvantages: Lower efficiency than more complicated devices such as turbine or piston expanders

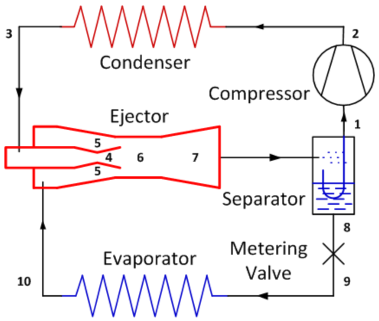


- Ejectors have found acceptance in CO_2 supermarkets recently, but **ejectors can work with any fluid and in any system *if applied correctly***

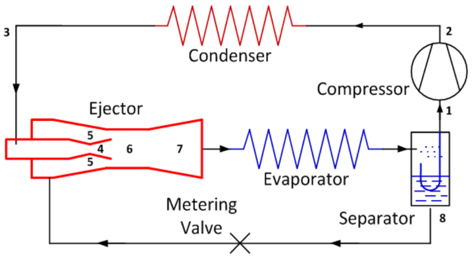
Evaporator Overfeed with Ejectors

- **Standard ejector cycle**:
  - Uses ejector to boost compressor suction pressure but can also be used to overfeed evaporator
  - Good for high pressure refrigerants like CO_2 but requires high ejector efficiency to be most effective
- **Ejector overfeed cycle**:
  - Uses ejector to recirculate liquid and overfeed evaporator
  - Good for low pressure fluids like NH_3 that are more sensitive to evaporator dryout due to low vapor density
  - Fewer active controls required compared to other ejector cycle, making ejector overfeed cycle potentially more suitable for small and medium scale applications
  - Can potentially provide very significant performance gains (depending on evaporator) for limited increase in system complexity

Standard ejector cycle

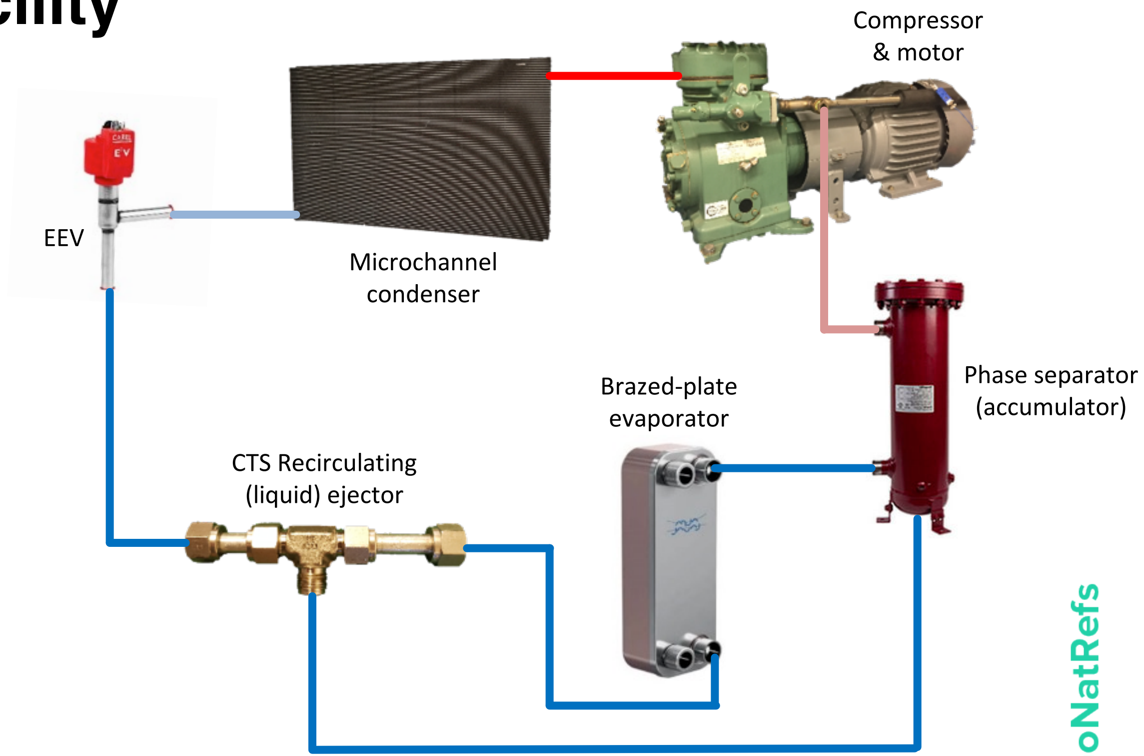


Ejector overfeed cycle



CTS Ammonia Test Facility

- CTS NH_3 chiller modified by adding ejector and phase separator for evaporator overfeed
  - COTS compressor, valve, phase separator, and brazed-plate; custom MC condenser; CTS in-house ejector design
- Baseline (DX without ejector) and ejector overfeed cycles evaluated at range of compressor speeds (900 to 1800 rpm) and heat source/glycol temps (0 – 20°C)



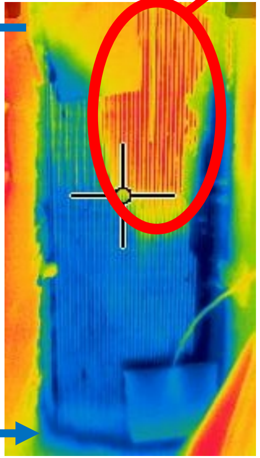
Effect of Overfeed on Evaporator Operation

- Infrared images of brazed plate can help show effect overfeed has on refrigerant temperature in evaporator

Significant superheated area in DX mode (lower ΔT between NH_3 and very low NH_3 heat transfer coefficient)

NH_3 outlet

Side view of BPHX



NH_3 inlet

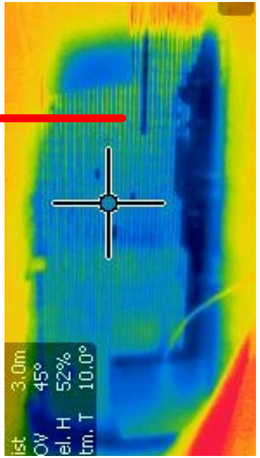
DX Cycle

T_{evap} = 2°C

ΔT_{SH} = 9 K

No superheated region, constant refrigerant temperature throughout (much better heat transfer coefficient and no reduction in ΔT)

Condition:
35°C condensing temp
1350 rpm compressor speed
20°C heat source temp



Ejec Overfeed

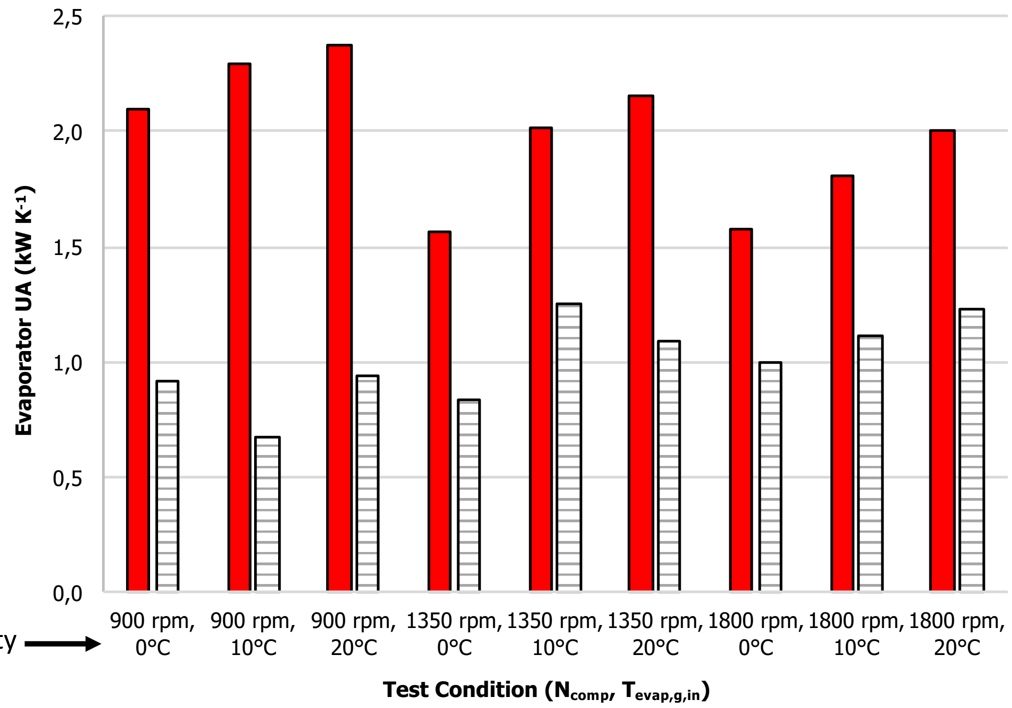
T_{evap} = 7°C

$x_{evap,out}$ = 0.78

Evaporator Performance Enhancement

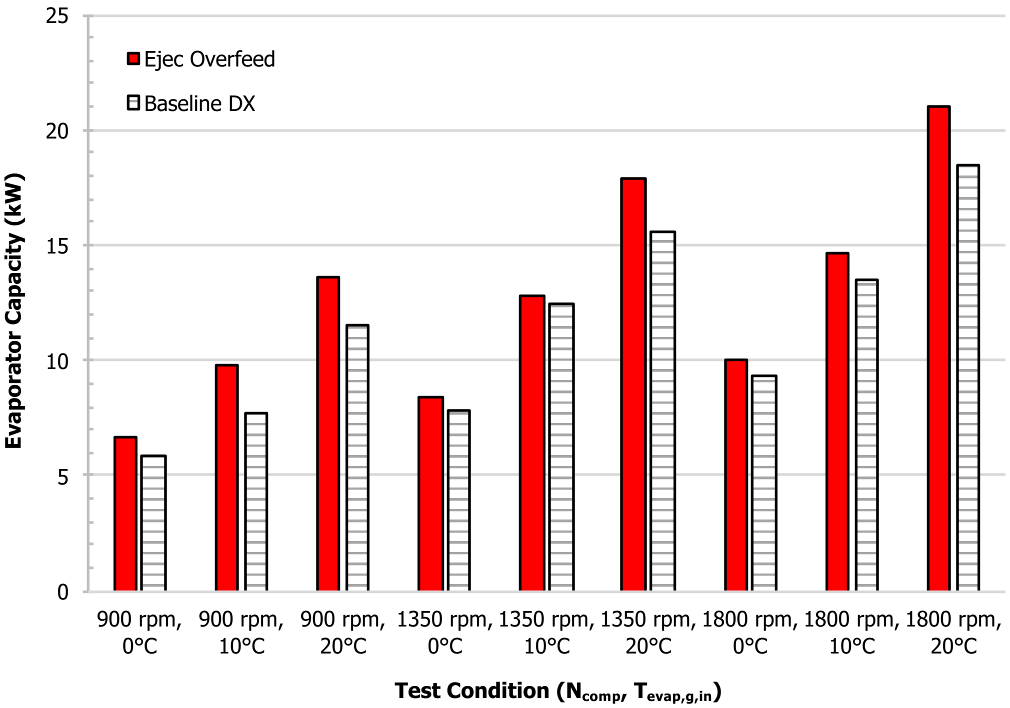
- Evaporator overall heat transfer coefficient (UA) improvement ranges from 60 to over 200 %, **2 – 6 K rise in evaporation temp with overfeed**
- Evaporator improvement is most significant at lower capacity
  - Lower capacity means over-sized evaporator, larger superheat region, and more opportunity to improve with overfeed

Cycles compared at multiple compressor speeds and heat source temps, representing a factor of 3x variation in capacity →



Capacity Improvement with Overfeed

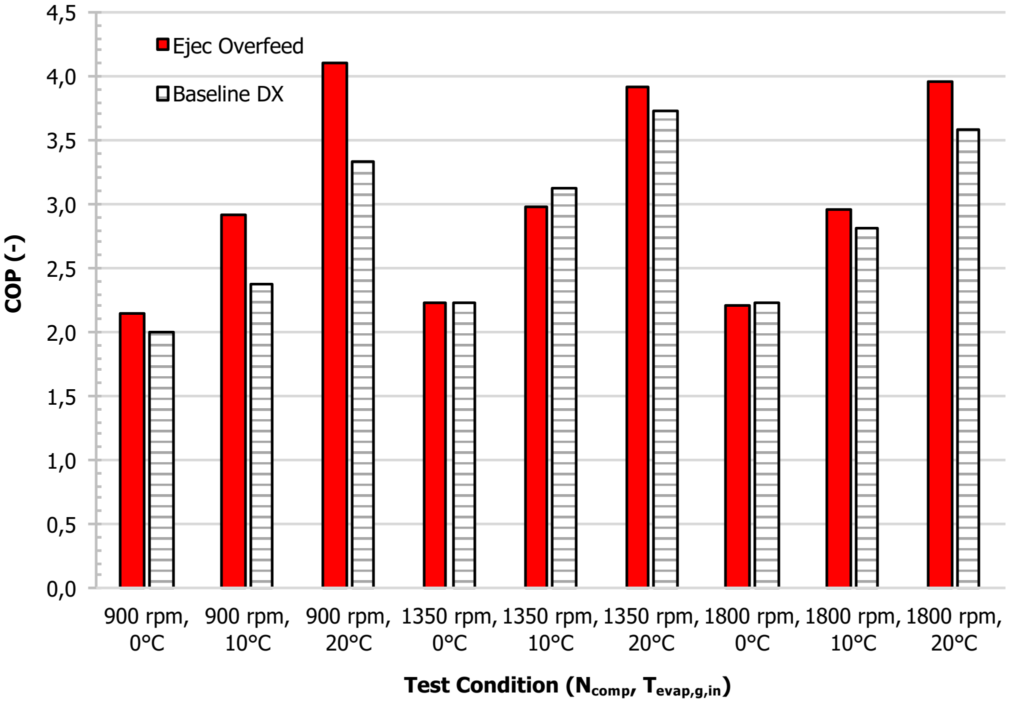
- **Capacity improvement ranges from 3 to 28 %**, with greater improvement observed at higher heat source temp
- Overfeed cycle has capacity in range from 7 to 21 kW
  - **Ejector can function over factor of 3x variation in capacity** and offer modest to very significant capacity improvements



Efficiency Improvement with Overfeed

- **COP improvement ranges from modest -1 to very significant 22 %**, with greater improvement at higher heat source temp and lower compressor speed

- These results show very promising opportunity to significantly boost NH_3 system capacity via overfeed without a significant increase in system complexity, though charge is increased



Conclusions

- Ammonia (NH_3) is a promising refrigerant due to its favorable efficiency and environmental friendliness but is limited in applicability due to toxicity concerns
  - Efforts to expand range of NH_3 applications include low-charge and indirect or chiller systems, though these decrease system efficiency
- Overfeeding the brazed plate evaporator in an NH_3 chiller (e.g. for domestic or commercial air-conditioning) using a recirculation (liquid) ejector is a promising method to improve ammonia system efficiency while still allowing the system to remain isolated
- The NH_3 chiller investigated in this study showed very significant simultaneous improvements in COP and capacity of up to 22 and 28 %, respectively, with the improvements being more significant at conditions where the evaporator was oversized for the system capacity

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Thank you for listening!