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A novel capacity control mechanism for two-phase ejectors in transcritical R744 air conditioners

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in collaboration with

#GoNatRefs

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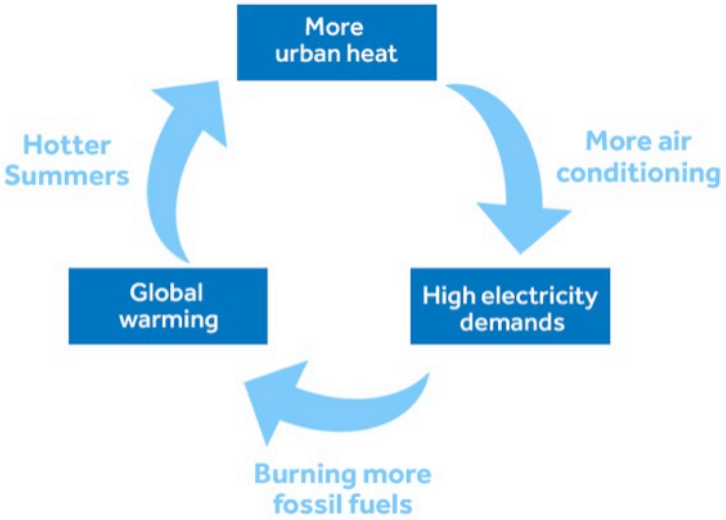
Agenda

- Background
- Research motivation
- Novel capacity control mechanism
- First experimental results in air conditioning mode
- Conclusions and future developments

Background: Air conditioning sector

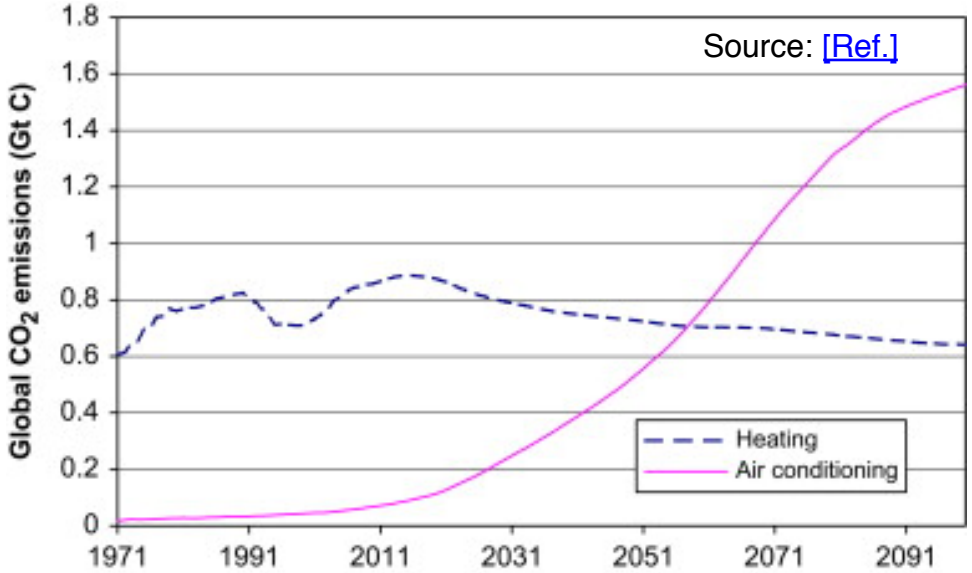
- Air conditioning applications are responsible for the largest energy demand (41% globally) in the cooling sector [Ref.]



- Over the next 30 years 10 AC units will be sold every second [Ref.]
- 4 times as many AC units than are in use today by 2050 [Ref.]

Background: Air conditioning sector(2)

- Large and ever-growing share market, **however…**



Urgent need for a highly efficient (< $TEWI_{indirect}$) air conditioner using an eco-friendly refrigerant (< $TEWI_{direct}$)…being **possibly safe**!!!

$TEWI_{indirect}$ = GHG emissions due to combustion of fossil fuels to generate power to run AC unit
$TEWI_{direct}$ = GHG emissions due to refrigerant leaks

Background: Why R744 two-phase ejectors?

- ODP = 0, GWP = 1
- A1 ASHRAE Classification

→ **Eco-friendly and safe refrigerant**

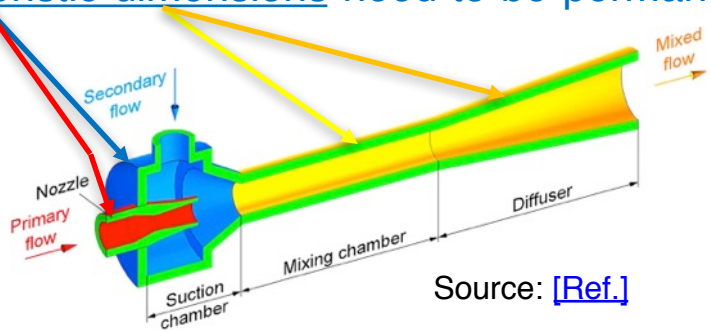
- Inexpensive
- Favorable thermo-physical properties
- Favorable performance in heating mode
- …

- COP improvements by up to 30% [Ref.] thanks to two-phase ejectors **at DESIGN conditions**

→ **Potentially highly efficient air conditioner**

Research motivation: Challenges with ejectors

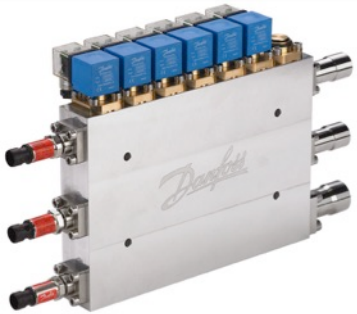
- Ejector-equipped transcritical R744 HVAC&R system performance dramatically penalized at off-design operations [Ref.]
  - 4 ejector characteristic dimensions need to be permanently suited to the operating conditions



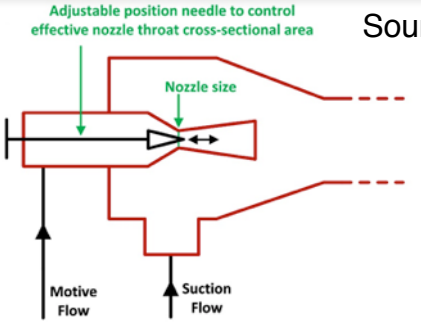
Source: [Ref.]

- Need to effectively control high pressure to maximize COP in transcritical R744 HVAC&R systems
  - e.g. -3%÷-17% in COP as $P_{high} = P_{high,optimal} \pm 5$ bar [Ref.]

Research motivation: Current status



Multi-ejector concept: too complicated [Ref.], expensive [Ref.] and limited by manufacturing size



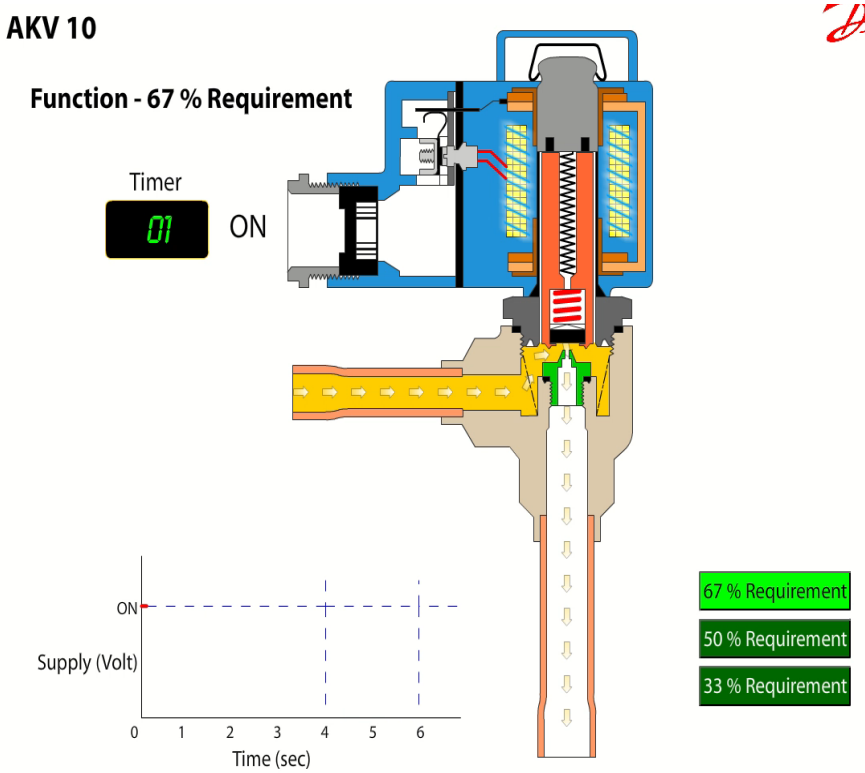
Source: [Ref.]

Adjustable needle: complicated and costly design, more friction losses are incurred, vulnerable to clogging [Ref.]

- At present, two-phase ejectors cannot be effectively capacity controlled without penalizing ejector and system efficiency in small-scale HVAC&R units

Novel capacity control mechanism: PWM ejector

- Novel capacity control methodology based on pulse-width modulation (PWM) of R744 flow through the ejector
  - Widely used methodology [link] in expansion valves by Danfoss
- PWM ejector features:
  - simplicity and low cost
  - low vulnerability to clogging
  - no practical size or application constraints

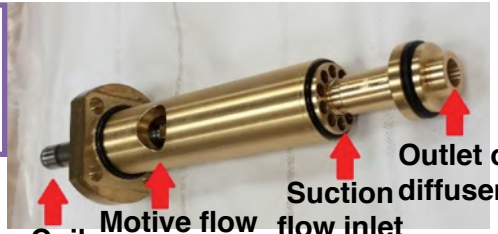


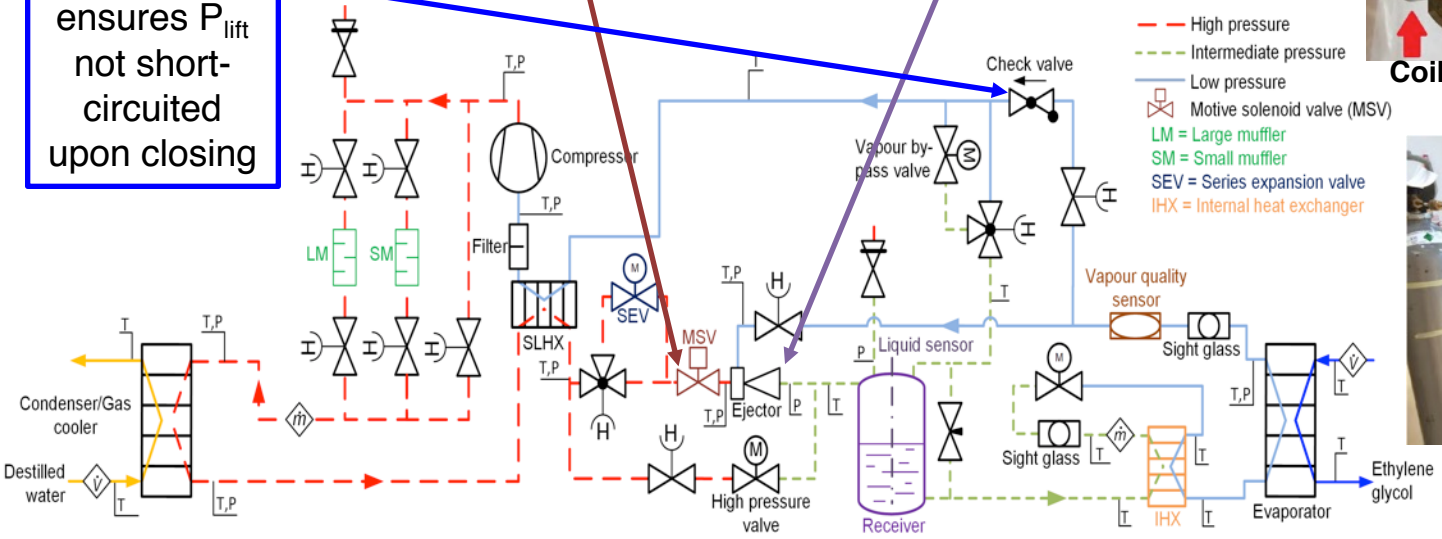
Novel capacity control mechanism: Research approach

Suction check valve ensures P_{lift} not short-circuited upon closing

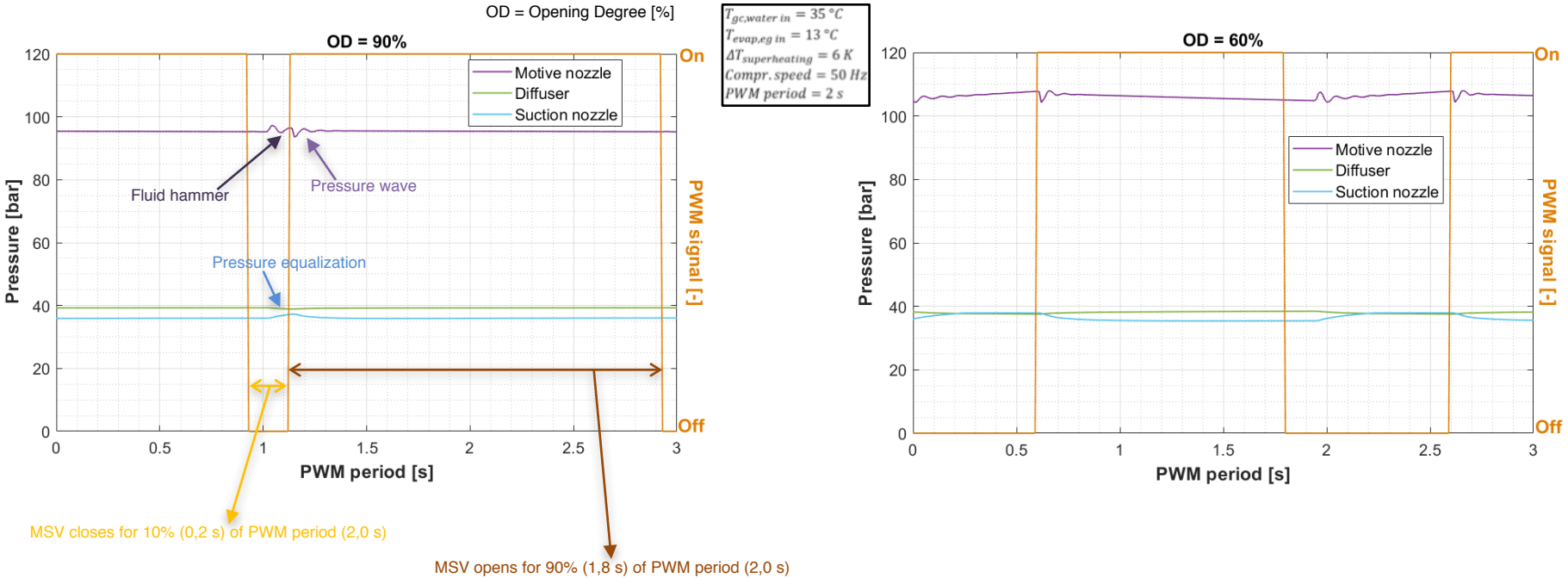
Motive solenoid valve (MSV) provides the PWM effect

Smallest ejector of the multi-ejector block (3 kW low pressure lift ejector)

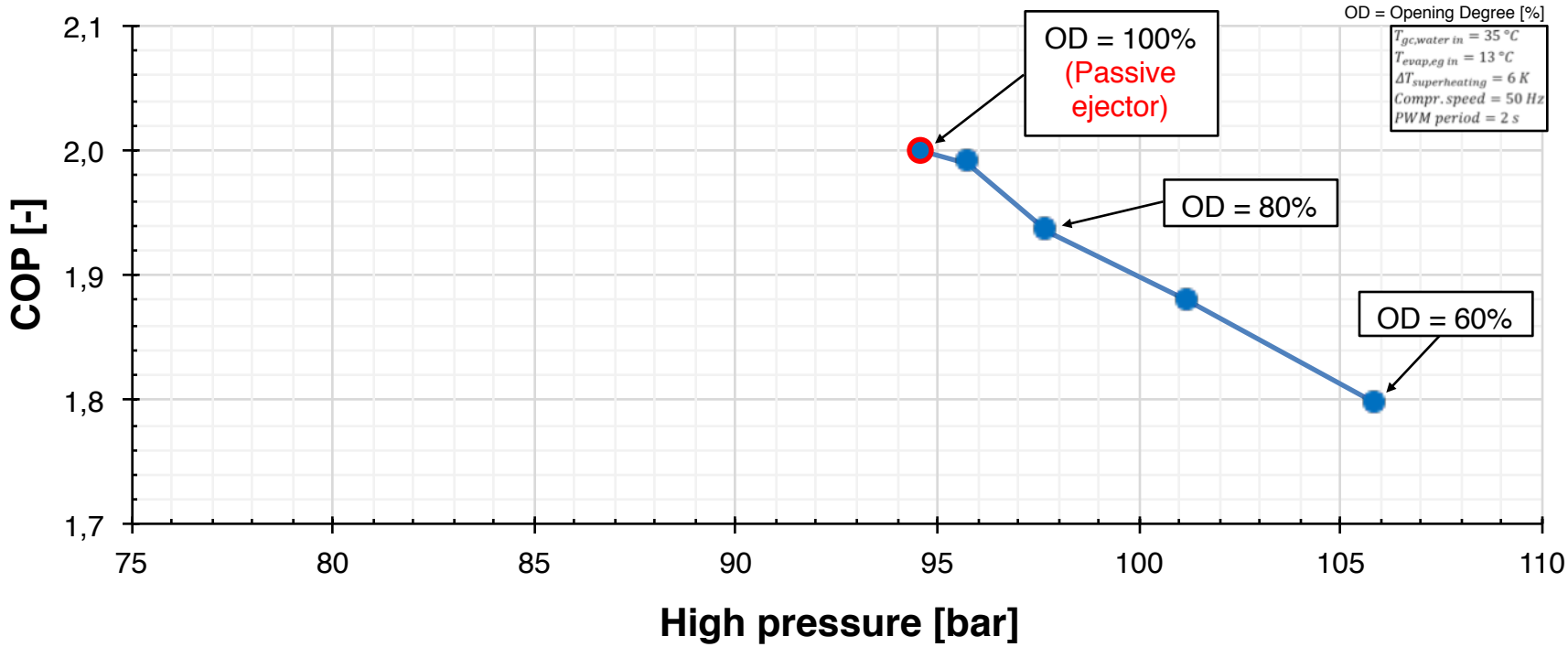




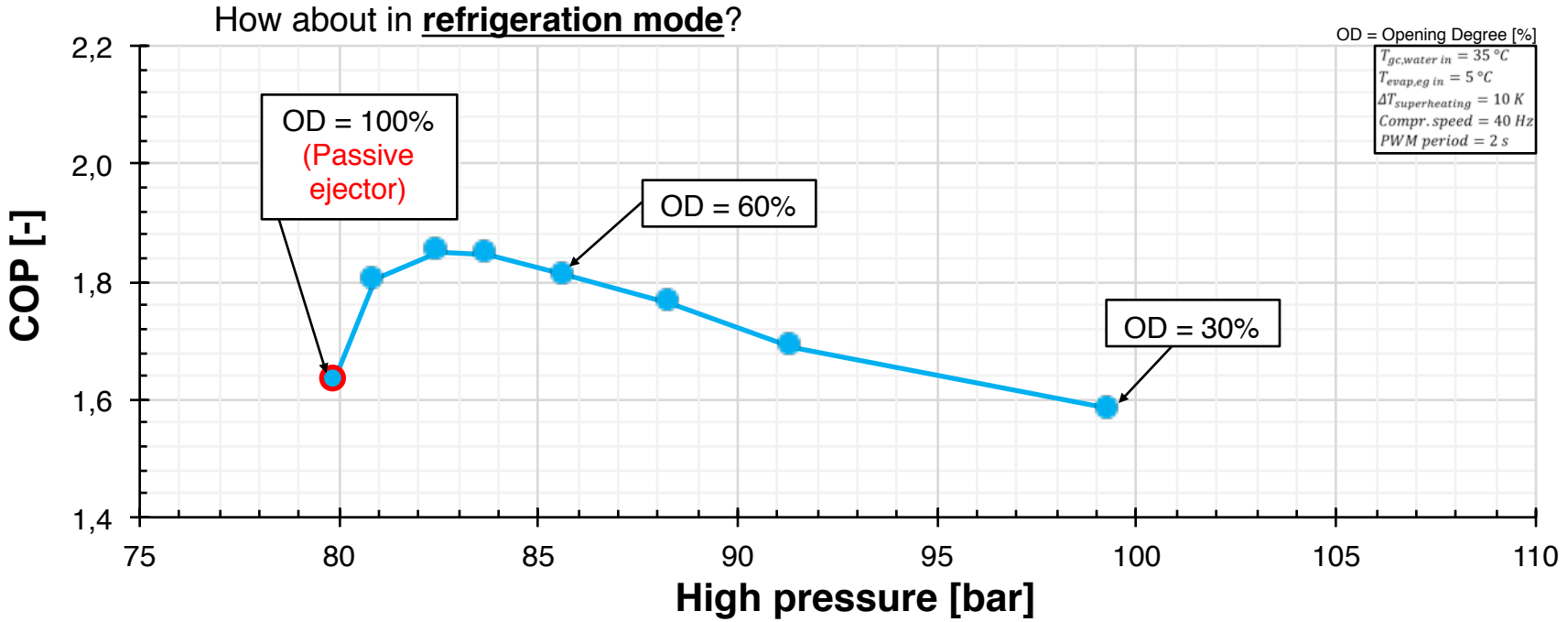
First experimental results in air conditioning mode



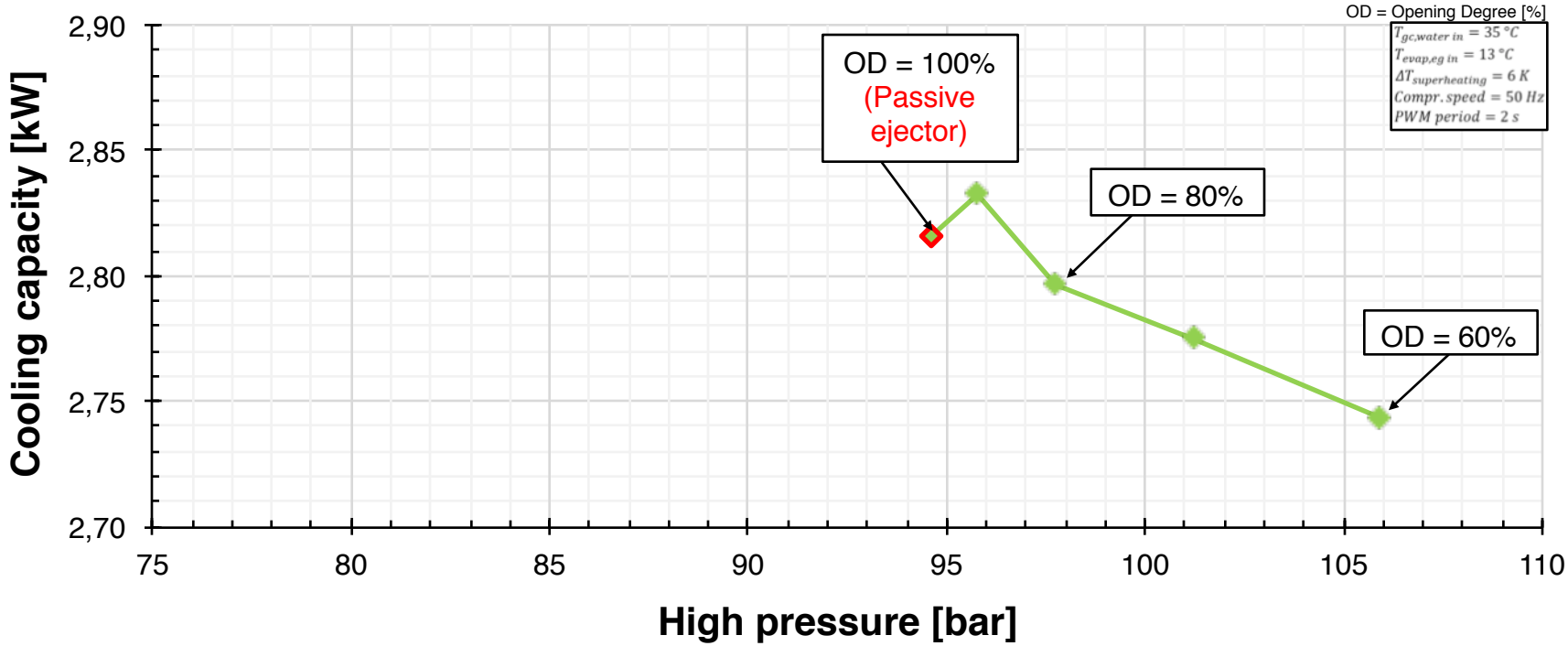
First experimental results in air conditioning mode(2)



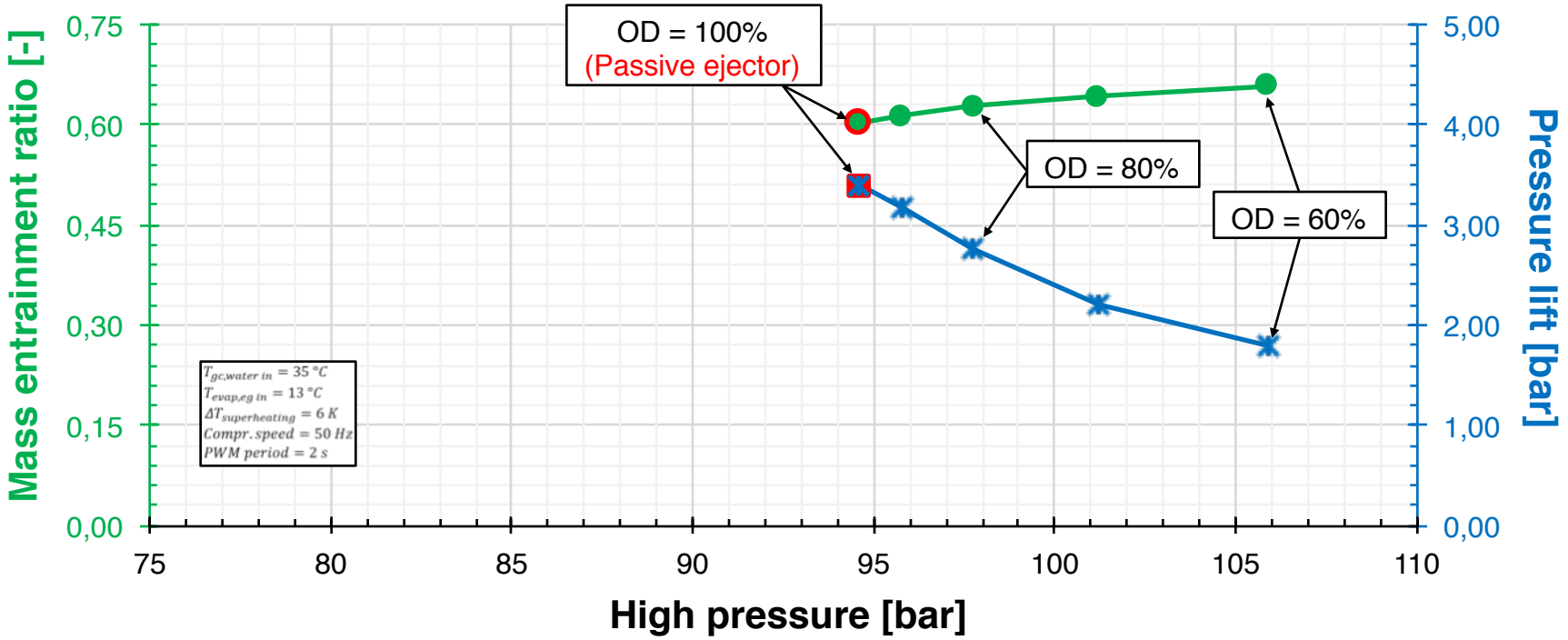
First experimental results in refrigeration mode



First experimental results in air conditioning mode(3)

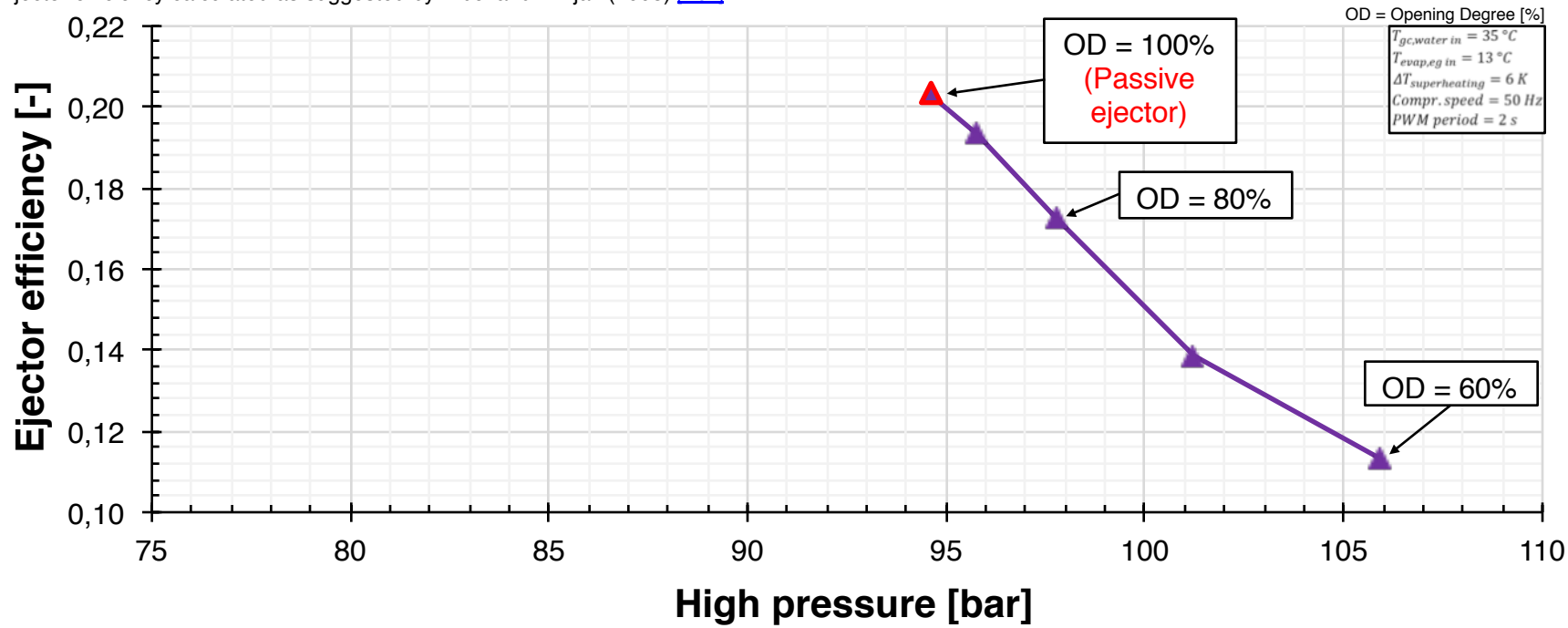


First experimental results in air conditioning mode(4)



First experimental results in air conditioning mode(5)

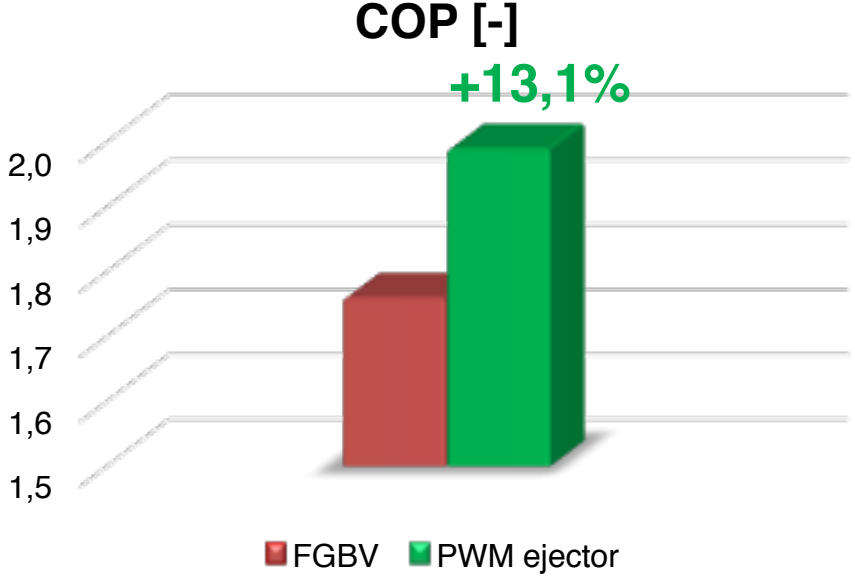
Ejector efficiency calculated as suggested by Elbel and Hrnjak (2008) [Ref.]

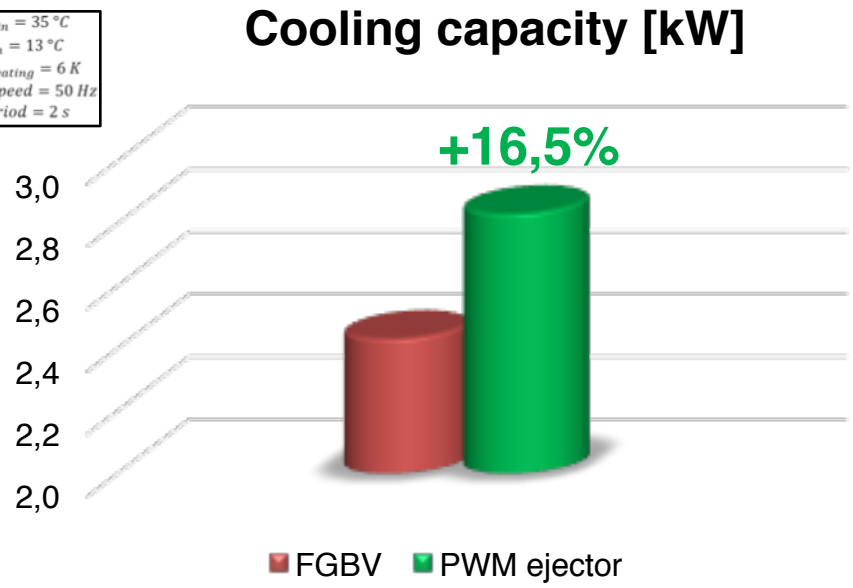


First experimental results in air conditioning mode(6)

System with flash gas by-pass valve and without ejector (FGBV) at optimal high pressure
vs.
System with PWM ejector with OD = 90%

$T_{gc,water\ in} = 35\ °C$
$T_{evap,eg\ in} = 13\ °C$
$\Delta T_{superheating} = 6\ K$
$Compr.speed = 50\ Hz$
$PWM\ period = 2\ s$





Conclusions

- PWM ejector permits controlling high pressure and maximizing COP in transcritical regime
- +13,5% in COP and +16,5% in cooling capacity compared to standard solution at $T_{gc,water\ in}$ = 35 °C in AC mode, respectively
- Further enhancements can be achieved by optimizing the ejector
- PWM ejector features simplicity, low cost, low vulnerability to clogging and no practical size or application constraints

Future developments

- Study of the compressor speed and $T_{gc,water\ in}$ effect
- Evaluation of optimum PWM period
- Assessment of adoption of mufflers featuring different size
- PWM control vs. series expansion valve control
- Evaluation of evaporator overfeeding

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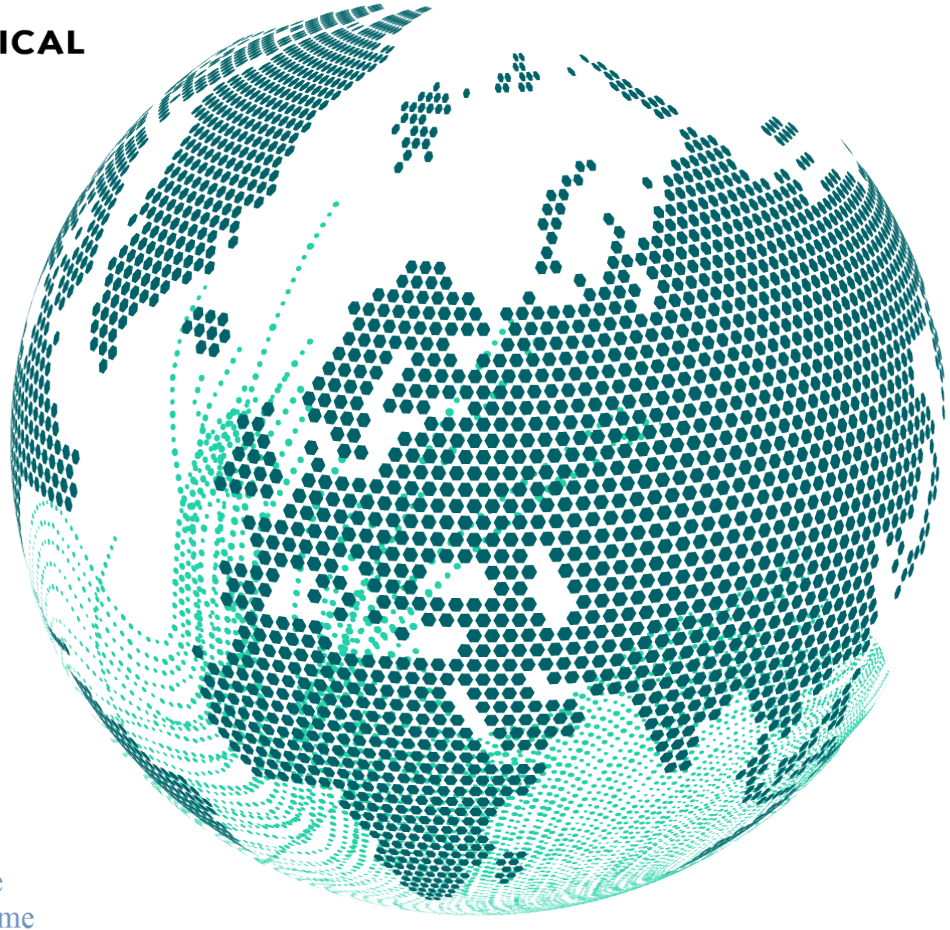

Thank you for listening!

Acknowledgements

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