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Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Online, non-intrusive composition measurements of circulating CO_2 based mixtures in an experimental heat pump by means of infra-Red spectroscopy

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Center for
High Performance
Buildings at Purdue

Introduction

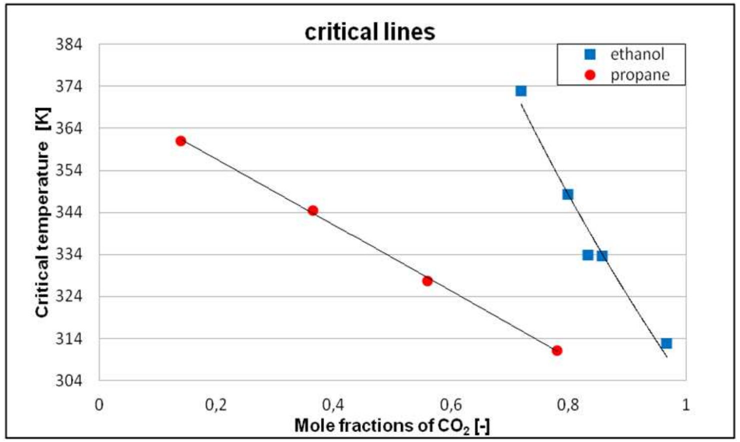
General context

Regulations & protocols	Aims
Montreal protocol	CFC & HCFC
Kyoto protocol	High GWP HFC
French RT2012 & EU ErP directive	Higher performances
F-gas revision	HFC phase-out

High need for harmless, “green” and efficient refrigerant alternatives.

Thesis main objective

Exploratory research on natural refrigerant mixtures, suited to domestic hot water and central heating production.



Sources: Galicia-Luna & Ortega-Rodriguez (2000) et Niesen & Rainwater (1990)

Introduction

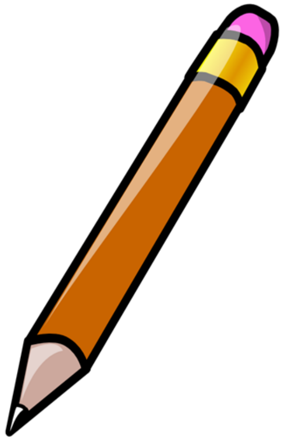
Previous works:

Authors	Topic	Remarks
Meunier *et Al.* (2005)	CO_2 + HFC mixtures for AC	REFROP predicted COP_C ↘ whereas bench tests showed COP_C ↗.
Kim *et Al.* (2007, 2008)	CO_2 + Propane	COP_C ↗, circulating composition is different from that charged.
Onaka *et Al.* (2008)	CO_2 + DME simulations	COP_H ↗ and is maximal with xDME = 10%

Simulations are not accurate enough due to the lack of accurate thermodynamic properties of such mixtures. Experimental heat pump loop along with refrigerant composition measurements are required.

Secondary objective: implementation of a non intrusive method for fluid composition measurements.

Summary



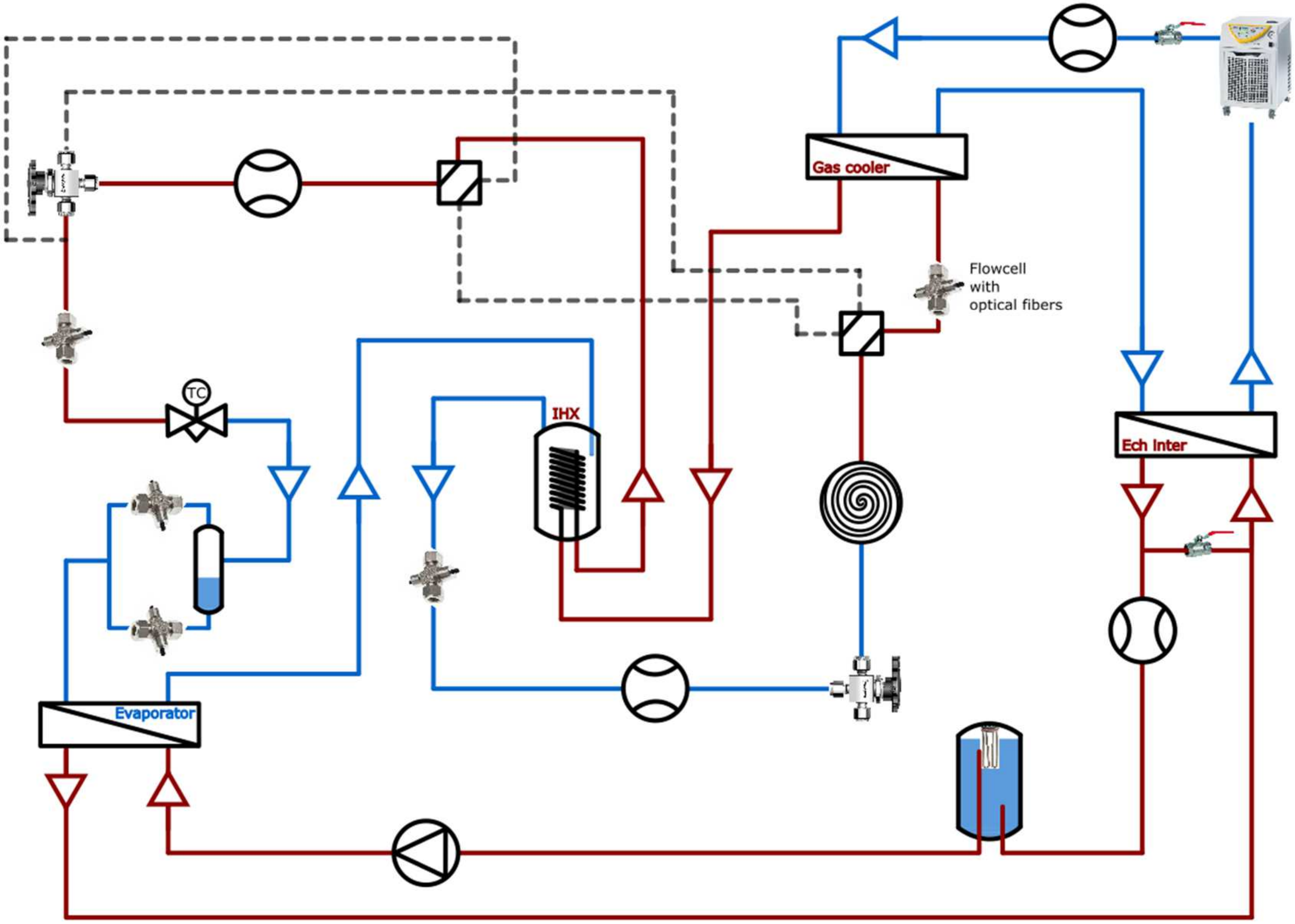
- Experimental setup
  - Experimental heat pump loop
  - Gas chromatography setup
  - Near infra-red spectroscopy setup
- NIR spectroscopy data
- Concentration models generation using PLSr
- First results for CO_2 + Propane mixtures as refrigerant
- Conclusion

Experimental setup

- CO_2 heat pump (2 to 5kW)
  - Scroll compressor with inverter.
  - Brazed plates evaporator and gas cooler.
  - Electronic expansion valve.
  - Internal heat exchanger with suction line accumulator.
- Gas Chromatograph
  - 3 Rolsi® micro samplers.
- NIR spectrometer:
  - Fourier transform spectrometer 10000 to 4500 cm^{-1}.
  - 8 ways optical multiplexer.
  - 5 on tube optical cells.

Experimental setup

- Scroll compressor with inverter.
- Brazed plates evaporator and gas cooler.
- Electronic expansion valve.
- Internal heat exchanger with suction line accumulator.
- Auxiliary water + glycol loops



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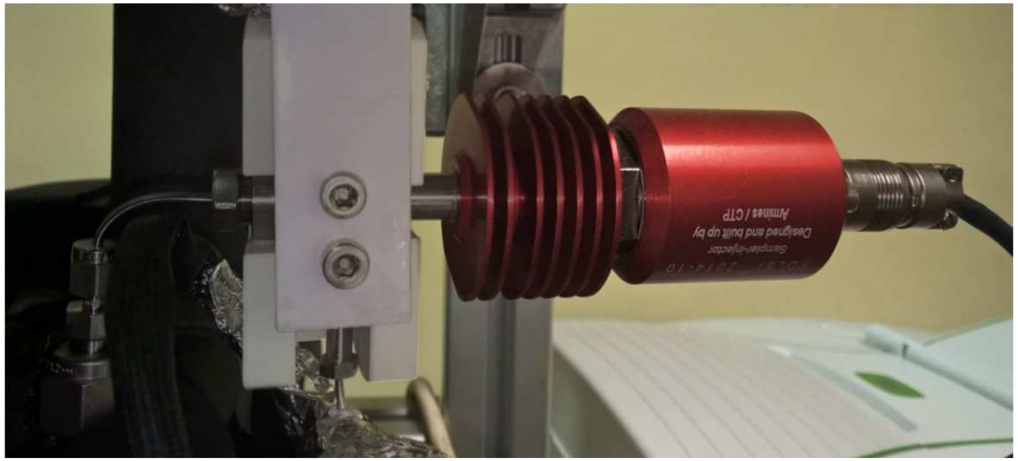
Gas chromatograph HP 5890

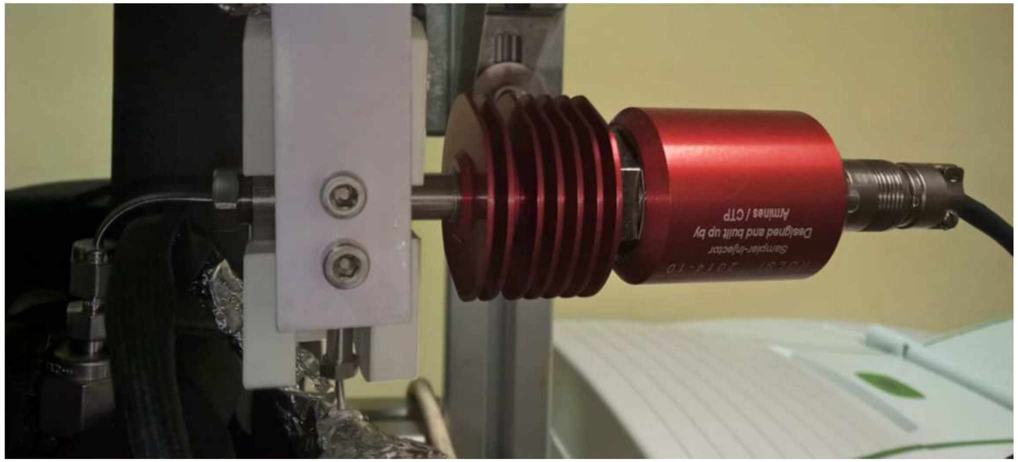


Rolsi ® micro-sampler

Experimental setup

- Gas Chromatograph
  - 3 Rolsi® micro samplers.
  - Helium transfer line for samples carrying

Gas chromatograph HP 5890



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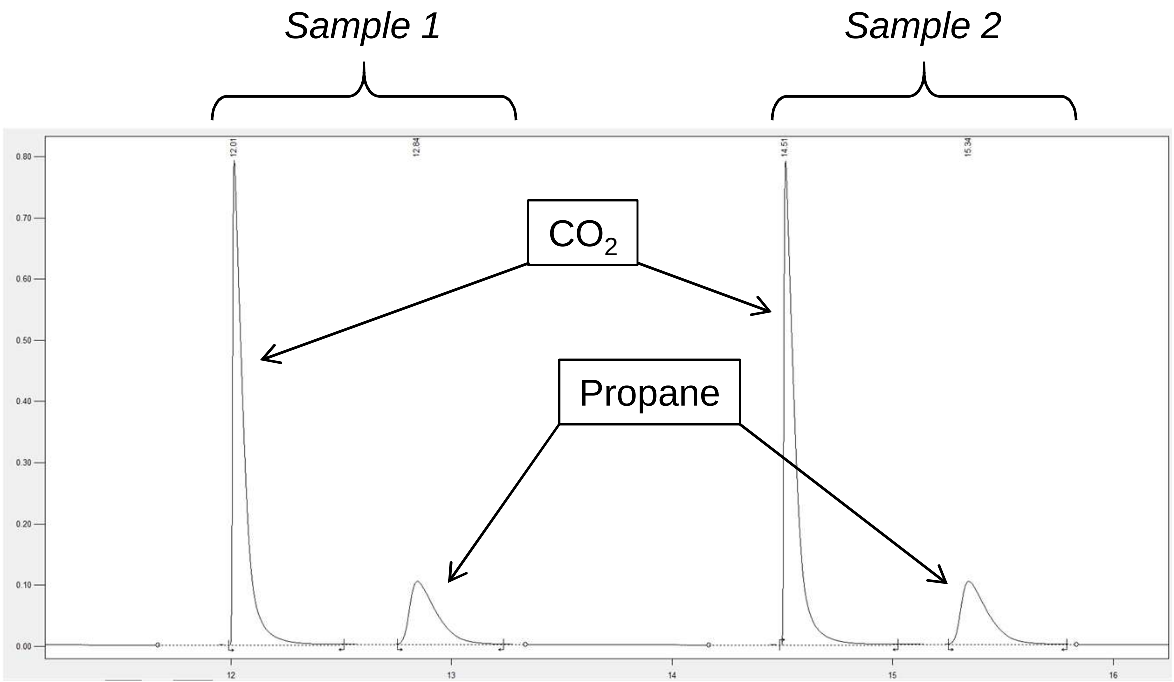
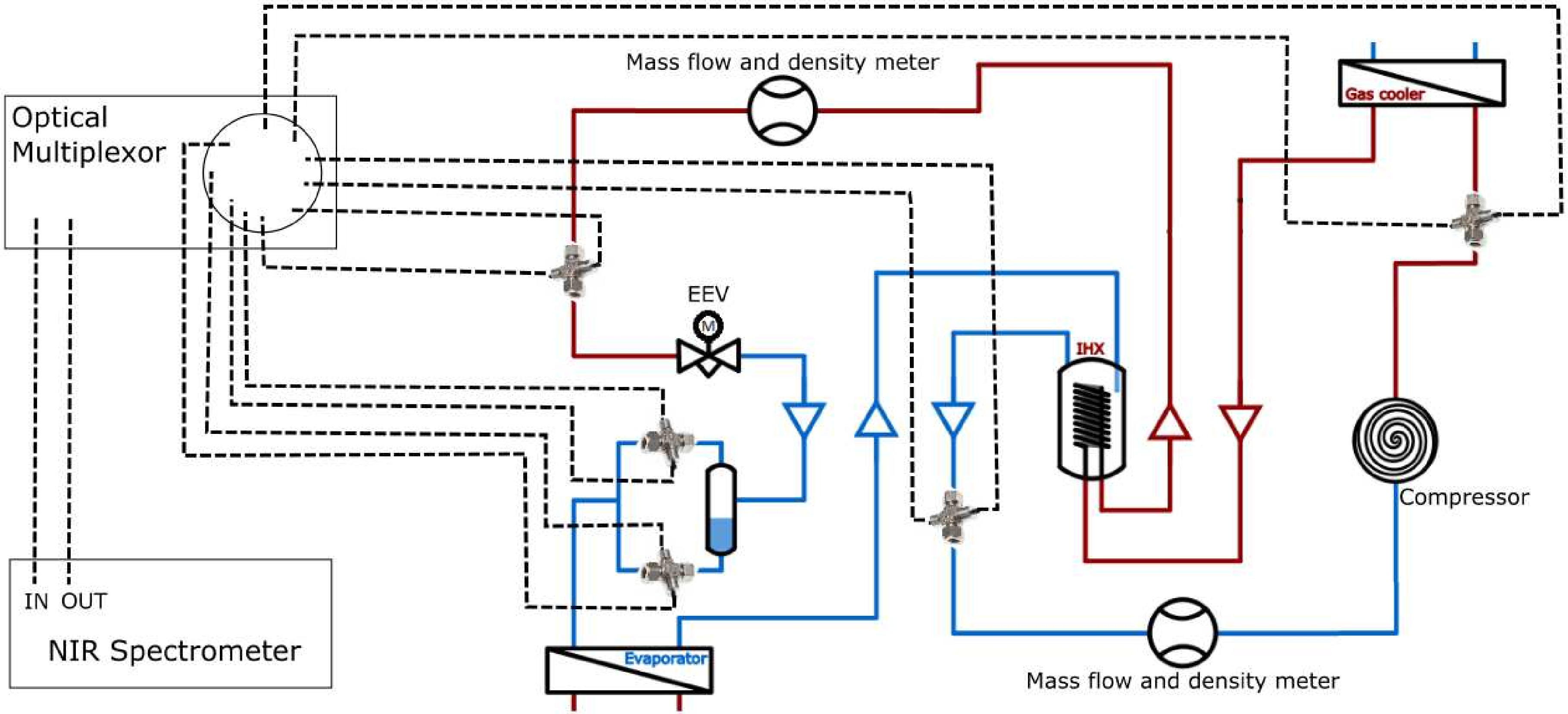


Nbr of Moles = f(peak area)

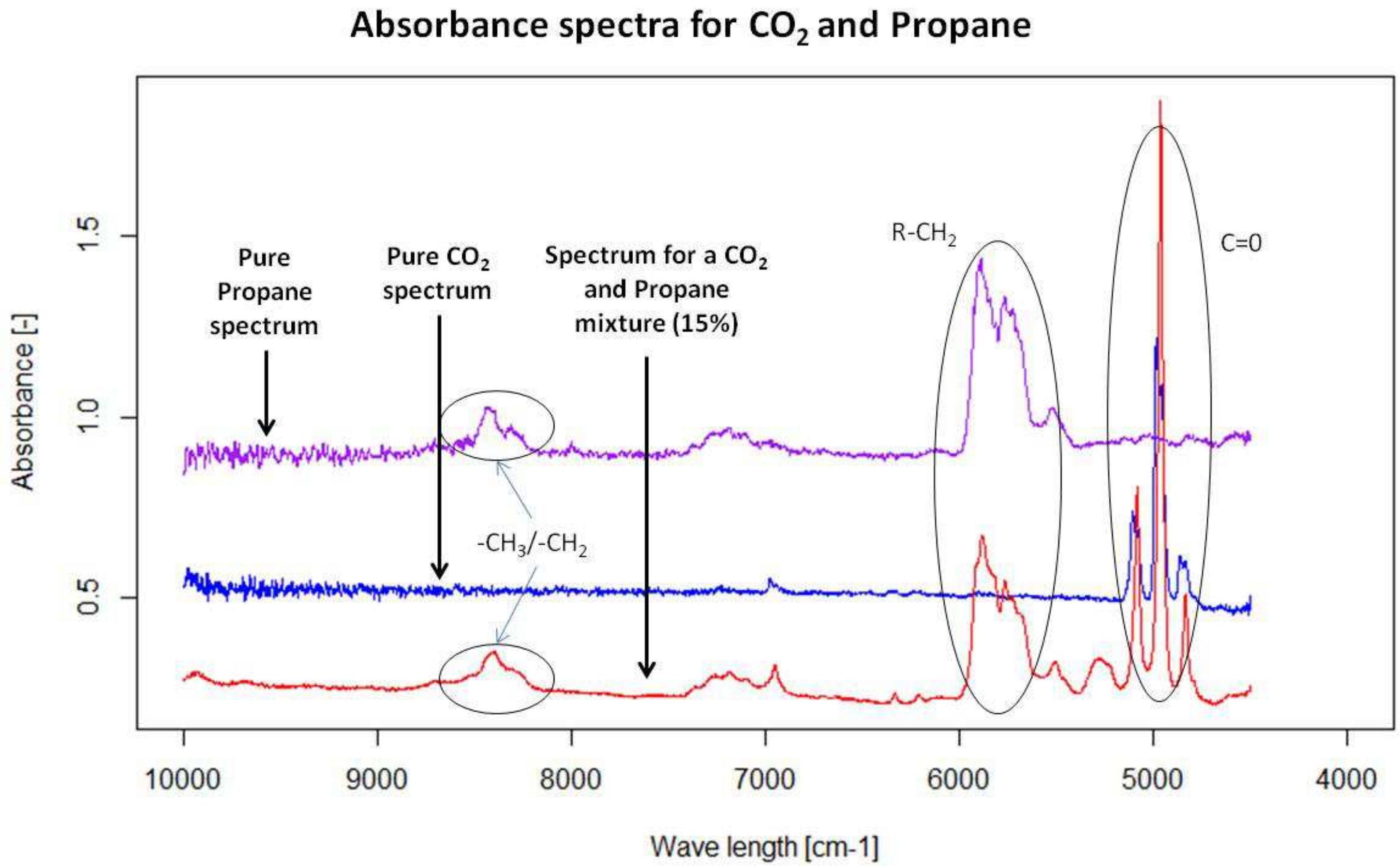
Slow & intrusive method for molar analysis of samples.

Experimental setup

- NIR spectroscopy setup



NIR Spectroscopy data



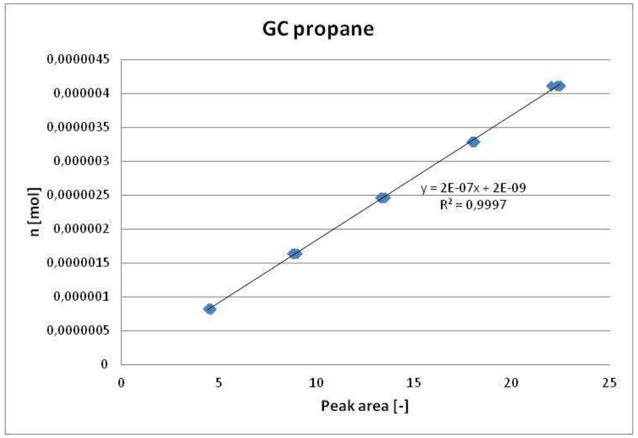
Fast & non-intrusive method for concentration analysis of circulating fluids.

Concentration models generation using PLSr

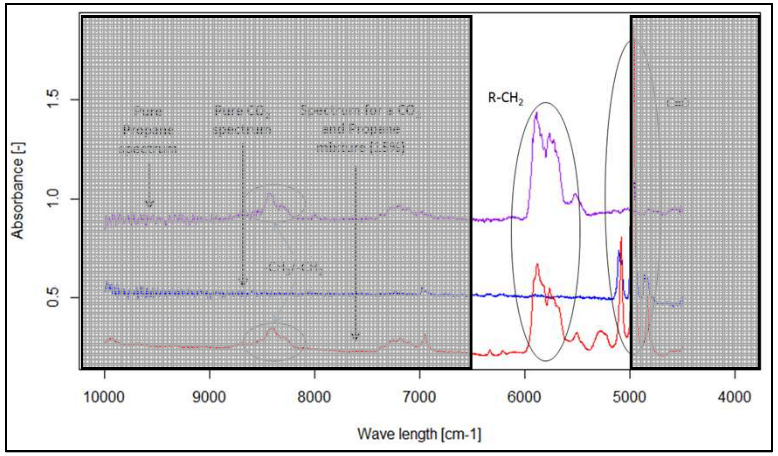
- Overhaul process

GC calibration → **Input data for concentration models calibration**

Successive injections of known molar quantities



n (mol) = a . peak-area



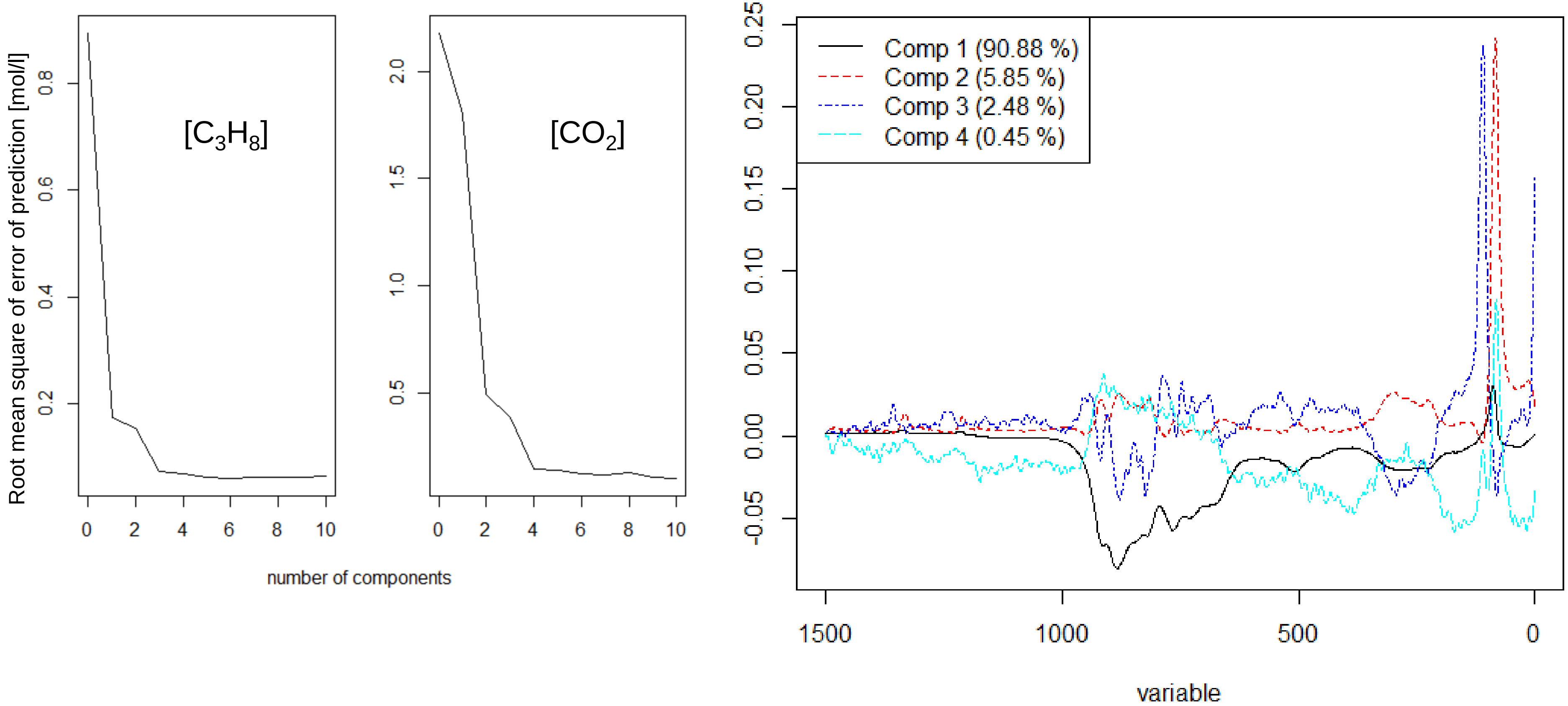
NIR spectra of mixtures with known concentrations (determined via GC).

Database

Aim: Elaborate models for [CO_2] and [C_3H_8] depending on spectral data (1500 variables)

Concentration models generation using PLSr

- The spectra database is processed through a Partial Least Square (PLS) regression algorithm (here with 10 random spectra used for cross-validation) *(Source: Chemometrics with R, by Ron Wehrens).*
- New variables, called Principal Components (PC) are determined.



Concentration models generation using PLSr

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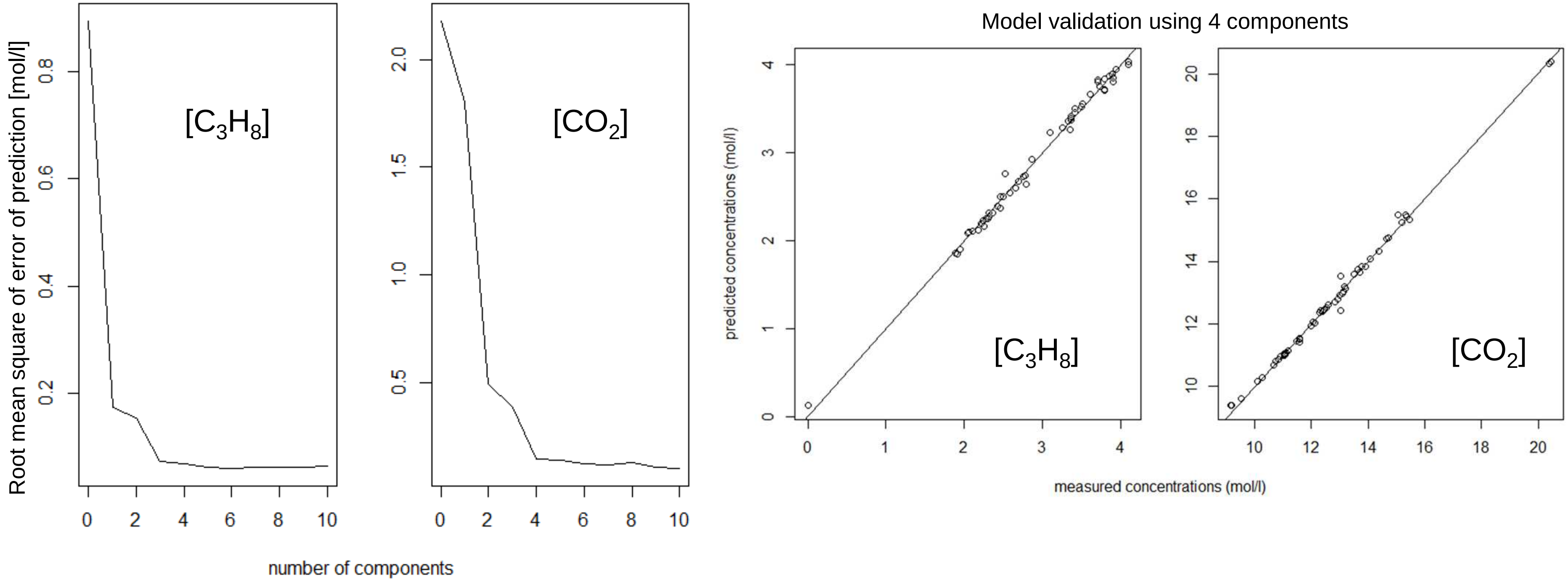
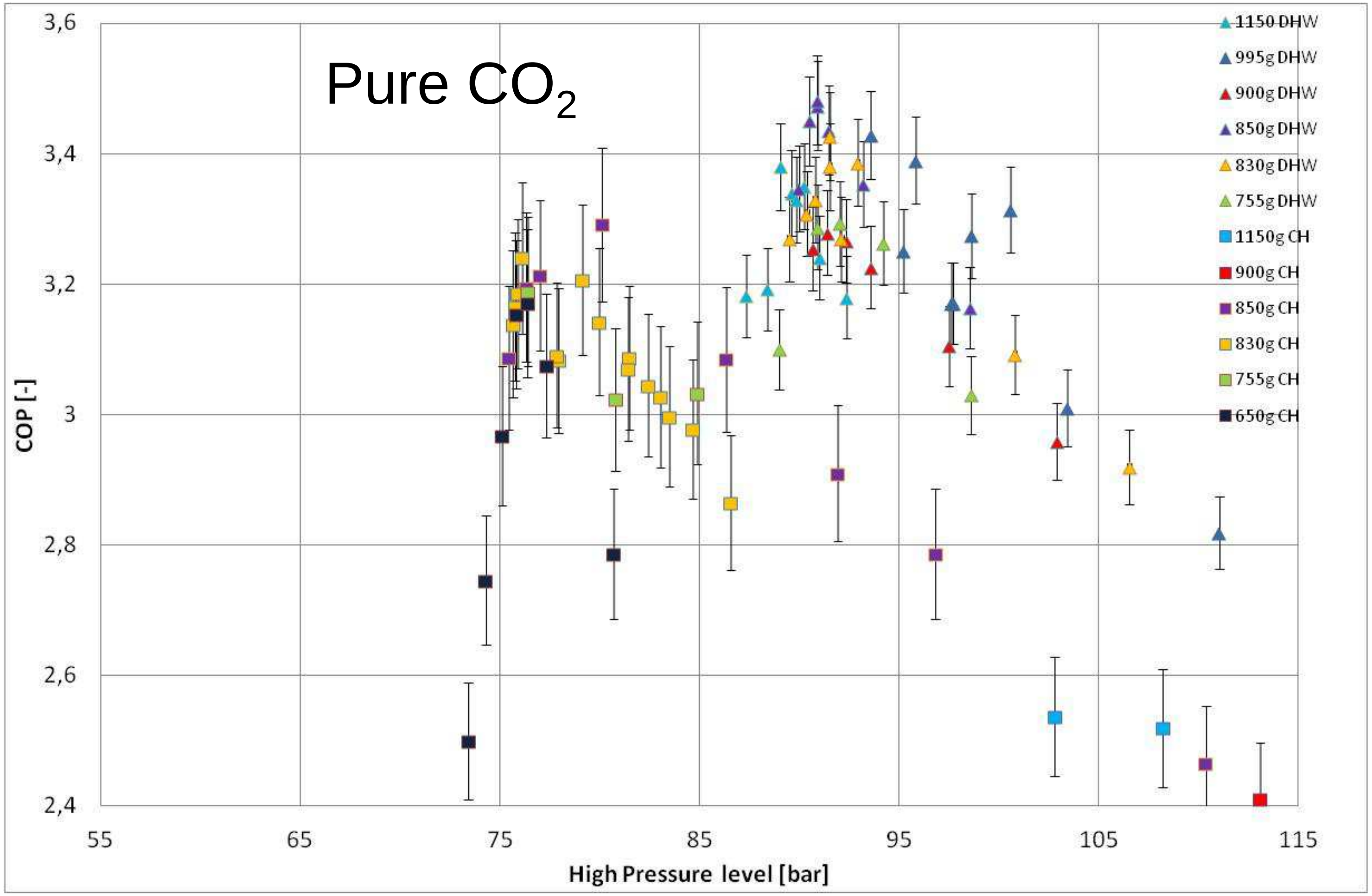


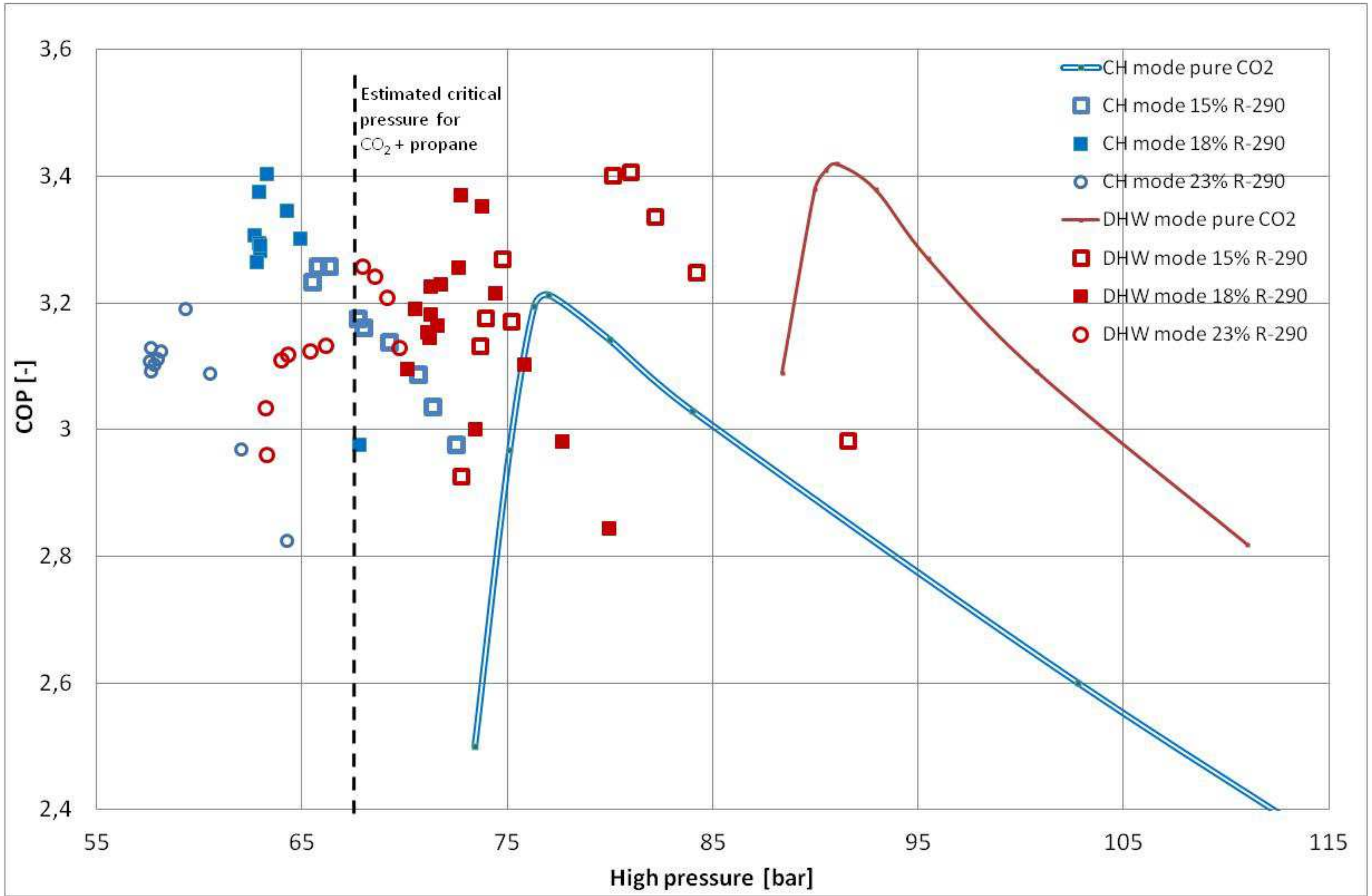
4 principal components end up here with a mean error of 0.07 mol/l (max 3.5%) for propane and 0.14 mol/l (max 1.5%) for CO_2.

Results for CO_2 + propane mixtures



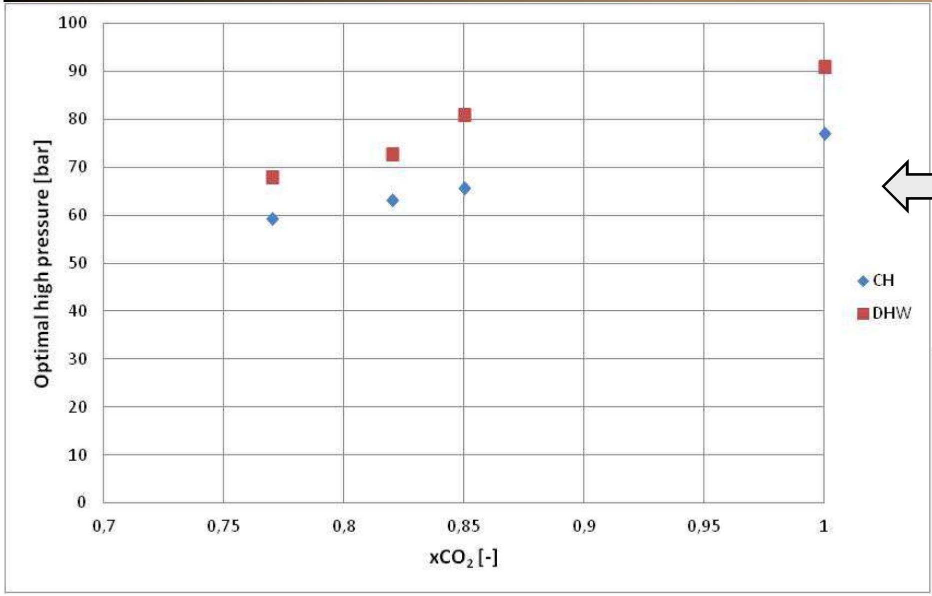
Refrigerant charge => available working points
Max COP for CH is 3.2 at 76 bar – Max COP for DHW is 3.4 at 92 bar

Results for CO_2 + propane mixtures



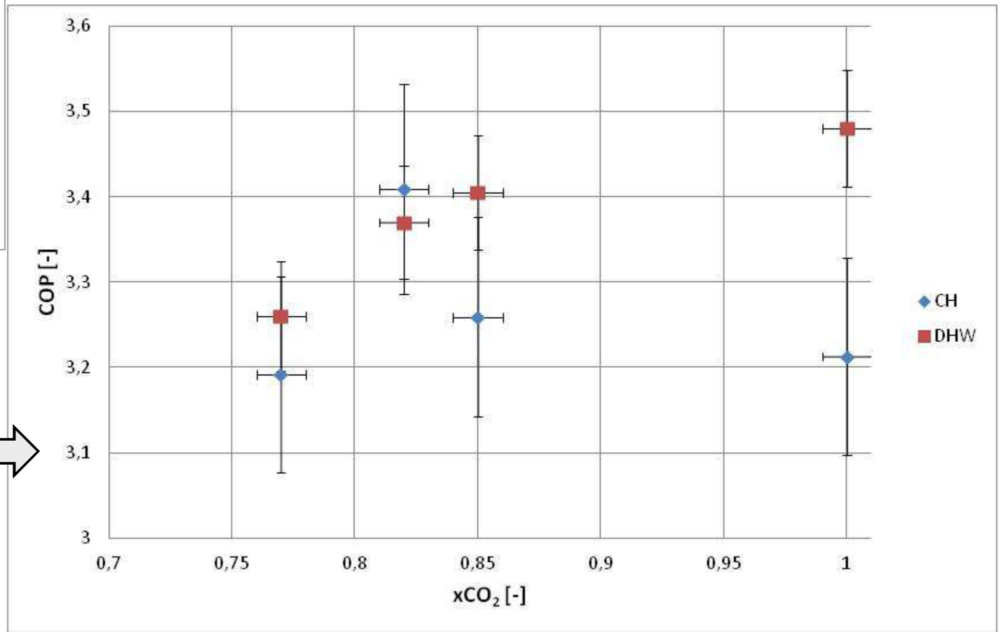
Subcritical cycles are available for central heating.

Results for CO_2 + propane mixtures



Addition of propane reduces the optimal high pressure

We observe a slight performance enhancement for central heating mode



Performance enhancements needs to be confirmed regarding the compressor efficiency.

Conclusion

- Design for a complete heat pump loop bench for mixtures studies.
- Composition of the circulating fluid can be monitored using an optical non intrusive method.
- Studies of CO_2 based mixtures are still ongoing, but a performance enhancement for central heating applications has already been observed.