Applying novel distillation techniques to the ASU of an IGCC with pre-combustion CO_2-capture

A HIDiC set-up for cryogenic total reflux experiments

Leen van der Ham[1], Michael Drescher[2] and Signe Kjelstrup[1]

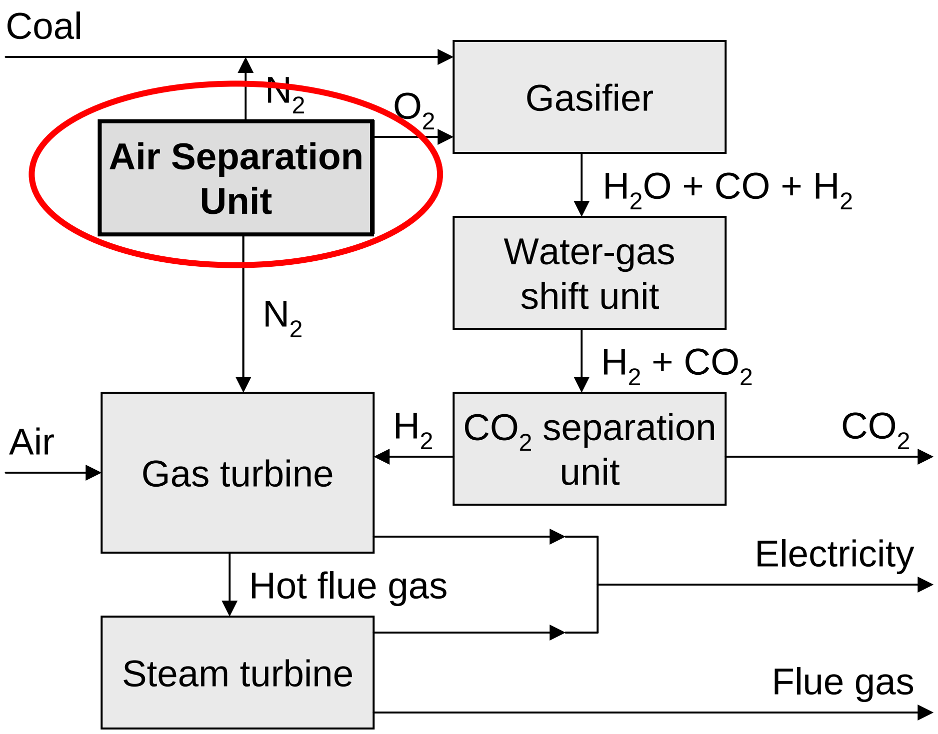
1. *Department of Chemistry, Norwegian University of Science and Technology, 7491 Trondheim, Norway*
2. *SINTEF Energy Research, Kolbjørn Hejes vei 1D, 7465 Trondheim, Norway*

June the 16th, 2011
6th Trondheim CCS conference

NTNU DECO2ARBit SINTEF

DECARBit – project overview*

IGCC with pre-combustion CO_2-capture



DECARBit looks at:

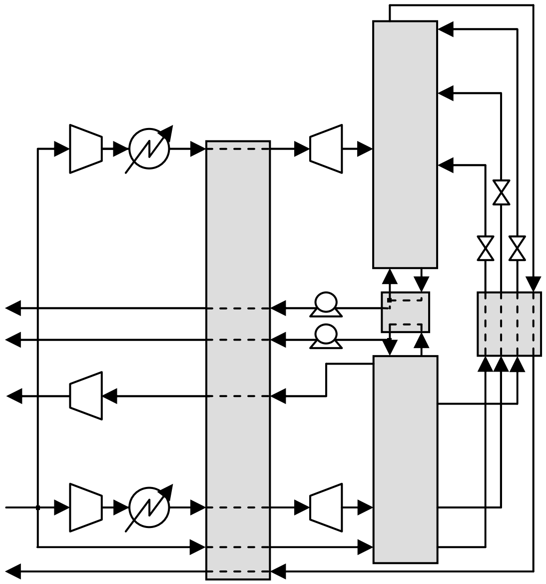
1. Process integration
2. CO_2 separation unit
3. Air Separation Unit
4. Gas turbine
5. Pilot plant testing

* Røkke and Langørgen, Energy Procedia 1, 1435-1442 (2009)

DECARBit – SP 3:
Advanced oxygen separation technologies

- Three alternatives are explored:
  1. Oxygen transfer membranes
  2. Sorbent based technologies
  3. Advanced cryogenic techniques

- Cryogenic techniques focuses on:
  1. Integration with other IGCC-units
  2. Main heat exchanger
  3. Novel distillation techniques

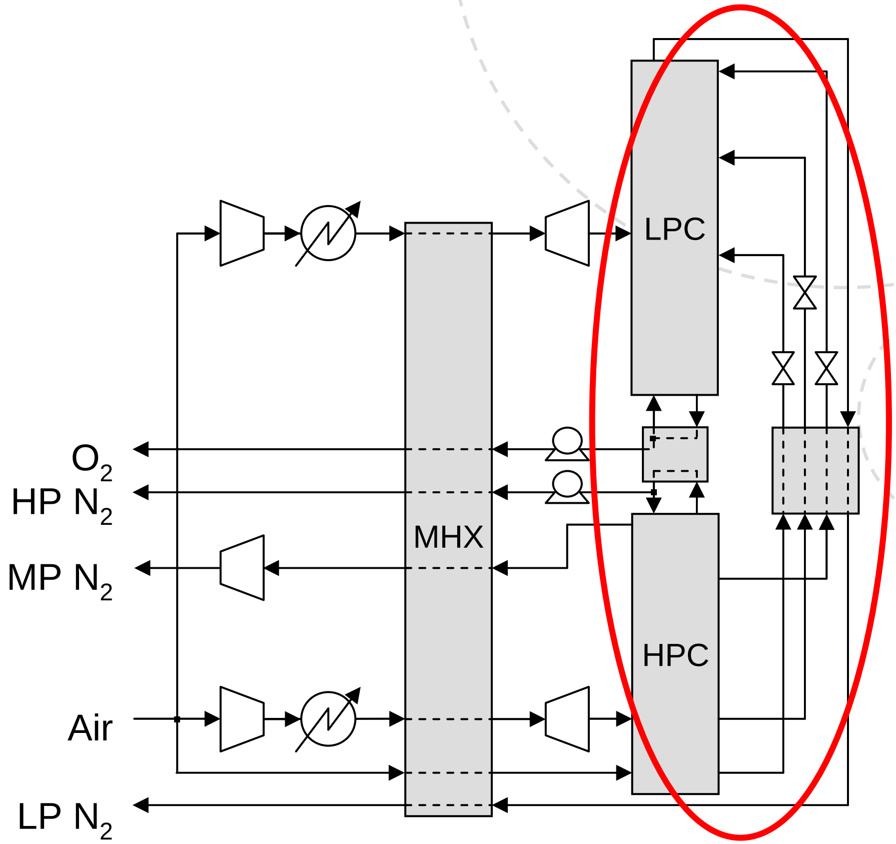


NTNU

Cryogenic Air Separation Unit
Two-column design

- Main process units
  - Main heat exchanger (MHX)
  - Low pressure column (LPC)
  - High pressure column (HPC)

- Distillation columns
  - Thermally coupled
    - Reboiler for LPC
    - Condenser for HPC



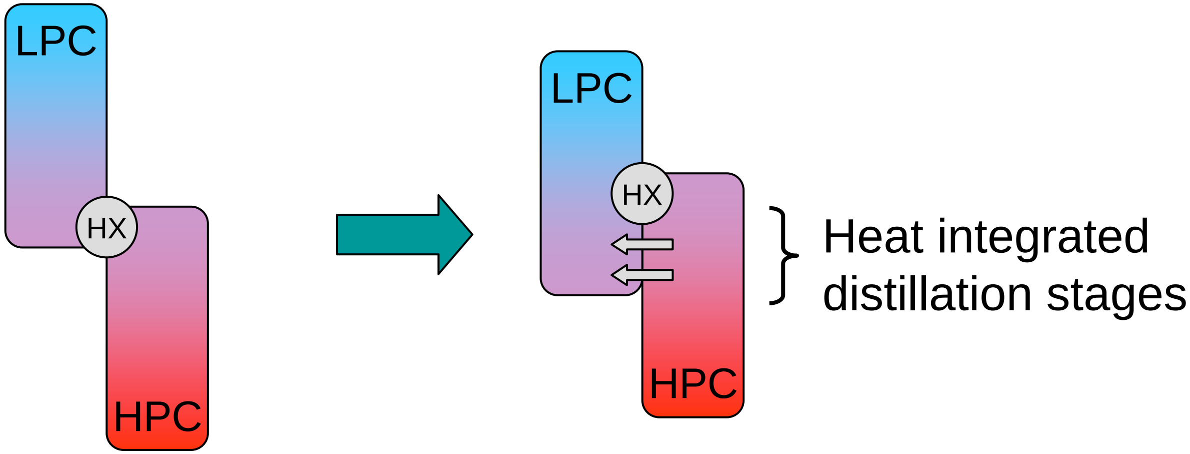
- Localization of irreversibilities using exergy analysis:
  - 26% is located in the distillation section*

NTNU

* van der Ham and Kjelstrup, Energy 35, 4731-4739 (2010)

Novel distillation techniques
Heat integrated distillation columns (HIDiC)

- Improving distillation efficiency:
  - Thermal energy transfer along the column height
- Applied to the columns of a cryogenic ASU:

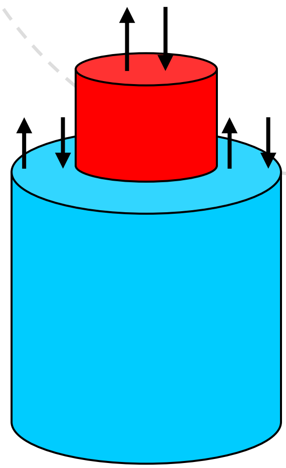


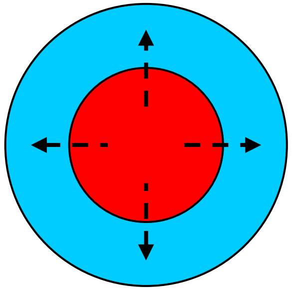
- Simulations predict a 23% reduction in irreversibilities*
  - But: uncertainties in some design parameters

* van der Ham and Kjelstrup, Ind. Eng. Chem. Res., accepted (2011)

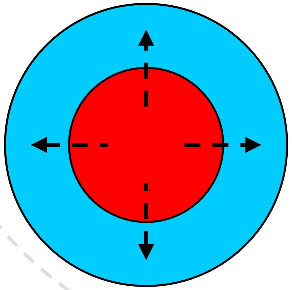
Heat integrated distillation stages
Practical implementation

- Cylindrical inner column
- Annular outer column
- Equipped with structured packing
- Difference in operating pressures
- Heat flux through inner wall
- Additional evaporation/condensation
- Flow rates vary along column height





Uncertain design parameters
Detailed problem background



- Performance of an annular column
  - More wall area per column volume
  - More sensitive to maldistributions in angular direction
- Overall heat transfer coefficient
  - Depends on operating conditions
  - Varies along the column height
- Effect of an additional heat flux
  - Introduces radial temperature gradients
  - Theory predicts an effect on the diffusional fluxes*
- Experimental investigations required!

NTNU

* van der Ham, Bock and Kjelstrup, Chem. Eng. Sci. 65, 2236-2248 (2010)

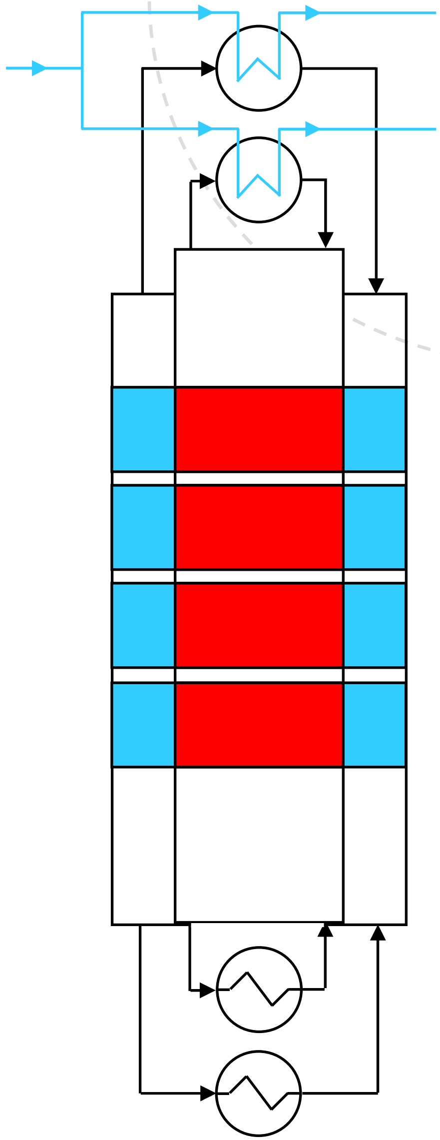
Experimental set-up
Requirements and goals

- Suitable for air separation
  - Cryogenic temperatures
  - Elevated pressures
  - High purity oxygen
- Assess the uncertain design parameters
  - Measured quantities
    - Achieved separation efficiency
    - Radial and angular gradients/maldistribution
    - Transferred thermal energy
  - Varying operating conditions
    - Column pressures
    - Column loadings

NTNU

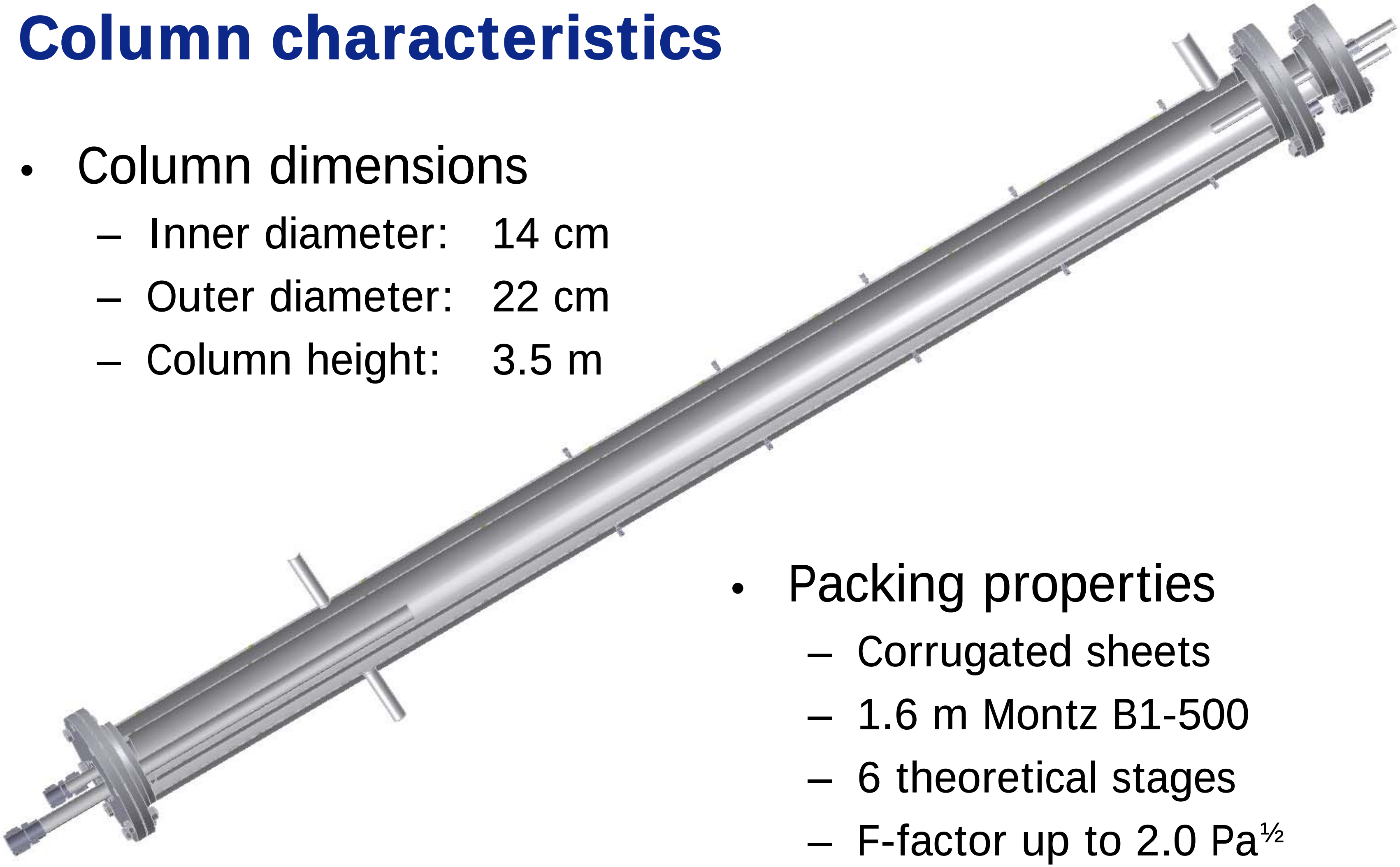
Experimental set-up
General design properties

- Two separate closed systems
- Total reflux operation
- Binary mixture of N_2/O_2
- Operational properties
  - Condensers
    - Plate fin heat exchangers
    - up to 550 kg/h liquid N_2
  - Reboilers
    - 20 kW electrical heaters
  - Maximum pressures
    - Outer column: 5 bar
    - Inner column: 20 bar



Experimental set-up
Column characteristics

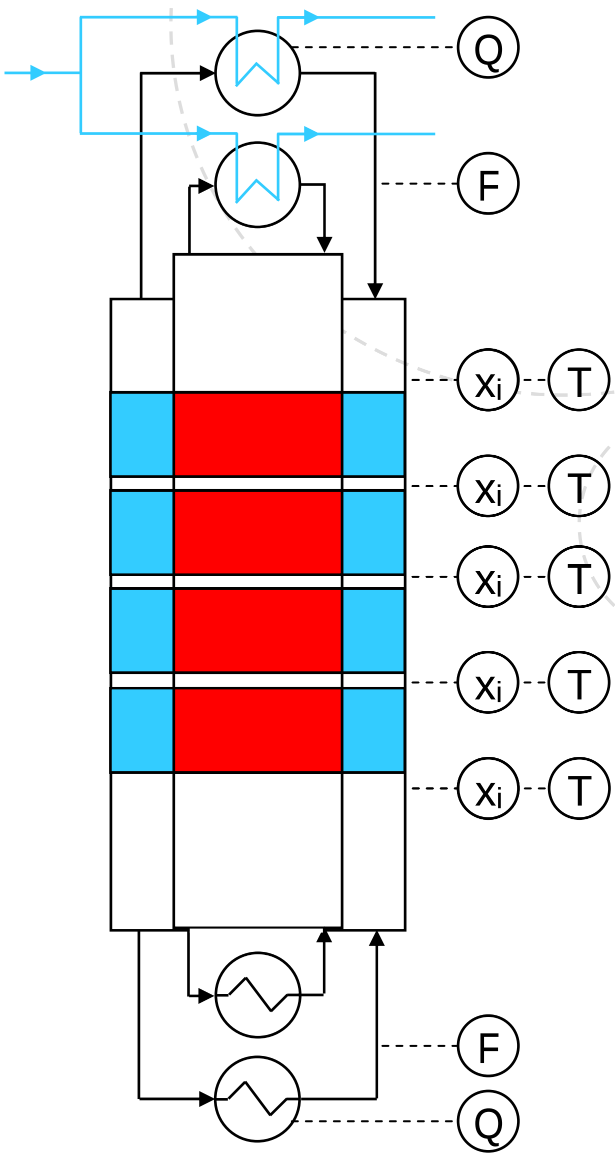
- Column dimensions
  - Inner diameter: 14 cm
  - Outer diameter: 22 cm
  - Column height: 3.5 m



- Packing properties
  - Corrugated sheets
  - 1.6 m Montz B1-500
  - 6 theoretical stages
  - F-factor up to 2.0 $Pa^{½}$

Experimental set-up
Measurement strategy

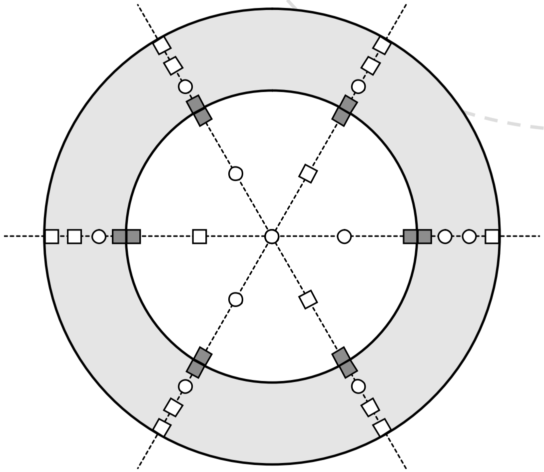
- Separation efficiency
  - Top and bottom compositions (x_i)
- Radial and angular gradients
  - Compositions and temperatures (T)
  - In both vapour and liquid phases
  - Measurements at several height levels
  - Multiple measurements per height level
- Thermal energy transfer
  - Reboiler and condenser duties (Q)
  - Top and bottom flow rates (F)



Experimental set-up
Instrumentation

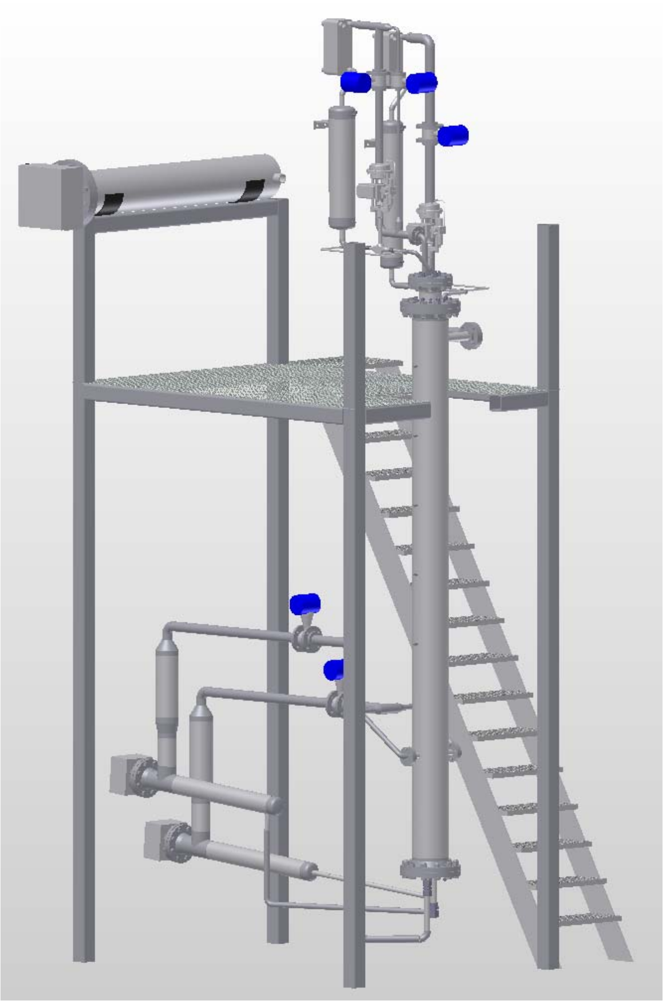
- External instrumentation
  - 7 flow meters
  - 4 control valves
  - 12 temperature sensors
  - 4 pressure difference sensors

- Internal instrumentation
  - 5 measurement heights
  - 2 absolute pressure sensors
  - 8 pressure difference sensors
  - 87 temperature sensors
  - 85 gas chromatography sample points



measurement points at height level 4 (counting from top)

Experimental set-up



NTNU

Conclusion

- Heat integrated stages can improve the ASU efficiency
- Experiments are needed for reliable predictions
- A set-up is designed to obtain the required data
- The set-up is under construction as we speak
- Experimental results will be available this autumn

Acknowledgements

- SINTEF Energy Research
  - Petter Nekså
  - Helge Johansen
  - Gunnar Lohse
  - Håvard Rekstad
  - Harald Mæhlum
- Air Liquide
  - Benoit Davidian
- The research leading to these results has received funding from the European Community's 7th Framework Programme (FP7/2007-2013) under grant agreement number 211971 (The DECARBit project).

Thanks for your attention