A New Reference Case for Benchmarking in the OCTAVIUS Project

PCCC2 – Second Post Combustion Capture Conference
Bergen, Norway, September 17-20, 2013

Hanne M. Kvamsdal
Senior Research Scientist
SINTEF Materials and Chemistry
SP1 leader of OCTAVIUS

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The Octavius Project (1)

- **OCTAVIUS**: **O**ptimisation of **C**O_2 capture **T**echnology **A**llowing **V**erification and **I**mplementation at **U**tility **S**cale
- **Based on previous EU projects CASTOR and CESAR**
- **5 year demonstration project (started March 2012)**
- The main objective:
  - *"Octavius aims to demonstrate integrated concepts for zero emission power plants covering all the components needed for power generation as well as CO_2 capture"*
- **Operability and flexibility** of first generation post combustion processes are demonstrated at 3 different pilot plants:
  - **Maasvlakte (TNO),**
  - **Brindisi (ENEL)**
  - **Heilbronn (EnBW)**

TNO: Massvlakte

ENEL: Brindisi

EnBW: Heilbronn

The Octavius Project (2)

- **Second generation process (DMX by IFPen)**
  - To be demonstrated at the Brindisi pilot if successful testing at a mini-pilot
- **Benchmarking of**
  - Some promising process configurations (based on literature and patent review)
  - DMX process
  - Reference capture plant based on results from the Cesar project

Overall benchmarking methodology

- Definition of reference case(s)
  - Source of CO_2
  - Real or generic
  - Site (or area) location (important for e.g. feed stream conditions, ambient temperature, cooling water conditions, costs) or typical values
- Definition of criteria for comparison
- Definition of a common basis (configuration and system boundaries, computational assumptions, methodology) for comparison
  - E.g. simulation tool for calculation of energy consumption
- Overall comparison (how to use the results obtained for each criterion)

European Benchmarking Task Force

- Objective:
  - *To develop a guideline for benchmarking of CO_2 capture technologies*
- Focus:
  - Building of a joint economic framework focused on using the same economic parameters (e.g. fuel prices, steel prices, dollar/euro exchange rate).
  - Building of a joint technical framework focused on a common working method for calculating technical performance of processes.
- Collaboration between three EU projects (Cesar, Ceasar, Decarbit)
- Finished in January 2011

Benchmarking in the OCTAVIUS project

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- Objective:
  - *To develop methodology for benchmarking of large scale post-combustion capture plant technologies*
  - *Draw conclusions from the technology and operational features demonstrated in the project for large scale capture plants*
- Focus:
  - Start with EBTF and then update and extend
  - Two base cases for the power-plant (800 MW_e bituminous coal case and 430 MW_e NGCC case) and site conditions as in the Rotterdam area
  - New reference case for the capture plant based on experiences from the CESAR project
  - Criteria for comparison
    - Will be based on the focus of research and demonstration in OCTAVIUS (emission, flexibility, and operability) in addition to energy and cost calculations
  - Benchmarking
    - New promising process configurations based on literature review and patent review using MEA and possibly also the CESAR 1 solvent (AMP+piperazine)
    - IFPENs DMX TM process

Criteria for comparison (1)

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- Plant net energy efficiency

$$\cdot_{\text{cycle}} = \frac{\sum \dot{W}_{th} \cdot \eta_{th\to e} - \sum \dot{W}_{\text{consumers}}}{\text{m}_{\text{F}} \cdot \text{LHV}}$$

- Costs
  - CAPEX + levelised cost (€/MWh$_{el}$) and/or avoidance cost (capture cost) (€/ton CO_2)

Quantitative criteria

Source: Kvamsdal et al. 2007, Energy

Criteria for comparison (2)

- **Environmental performance of the plant**
  - Chemical emissions (target: <4.3 ppmv amine/6.9 ppmv NH_3)
  - Waste and water consumption (cooling and process)
- **Flexibility**
  - Ability to change capacity and/or delayed regeneration of the capture plant based on upstream varying load
  - Still uncertain how to use it as a criteria for benchmarking
- **Operability/controllability (operational challenges)**
  - Highly related to the level of heat- and process integration
  - Can quantify:
    - The number of interacting subsystems
    - Number of recycle streams
    - Heat integration as heat transfer relative to fuel LHV
    - Number of main process units
  - Classification of operational challenges:
    1. Low
    2. Medium
    3. High

Quantitative/ qualitative criteria

Source: Kvamsdal et al. 2007, Energy

Development of the same basis for comparison - Simulation for efficiency and cost data input (1)

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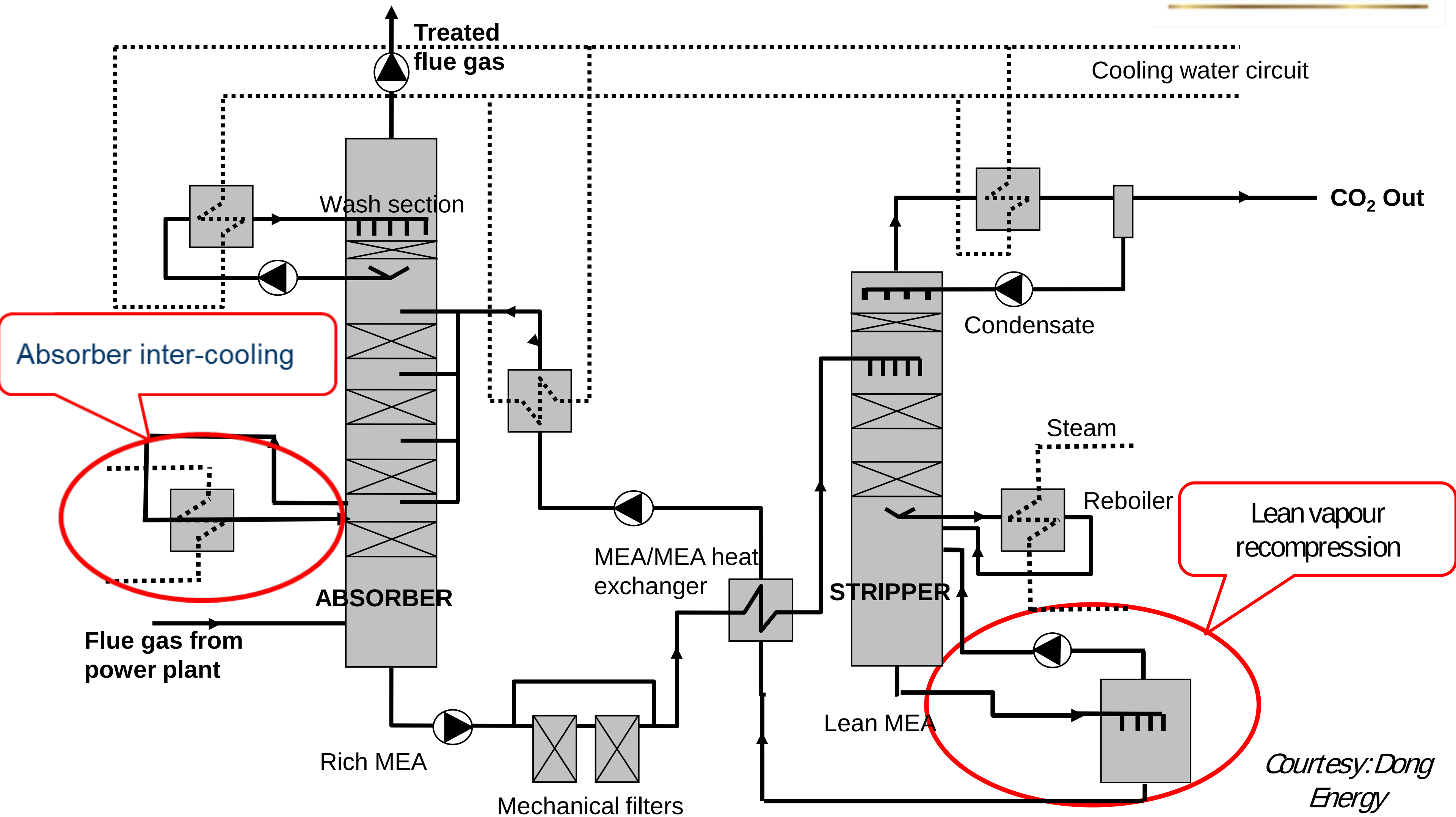
- **Same simulation tool(s) for all technologies (included reference)**
  - In Octavius: *many partners and preferences*
  - Tools to be used: Ebsilon for power-plant, Aspen Plus with RateSEP and CO2SIM (SINTEF/NTNU in-house tool) for capture plant + in-house tools for cost estimations
  - Several tools/models, but will be compared and adjusted before benchmarking
- **The same thermodynamic method**
- **System boundary**
  - Include all units contributing to the difference in efficiency e.g the compression part doesn't need to be included if its inlet conditions are the same

Development of the same basis for comparison - Simulation for efficiency and cost data input (2)

- Modeling – level of details
  - E.g. rate based model for the absorber
- Computational assumptions
  - Unit operation model parameters
    - E.g. pressure drop, heat exchanger temperature specification, turbine efficiency
  - Stream specifications
    - E.g. fuel, ambient conditions, CO_2 transportation pressure, steam pressure and temperature, gas turbine inlet temperature, condenser pressure
  - Others
    - E.g. ambient conditions, cooling water inlet and outlet temperatures, process water temperature, cost of utilities

New reference case for OCTAVIUS based on Esbjerg pilot plant and CESAR results



Courtesy: Dong Energy

Reference case(s) for OCTAVIUS (1)

- **Based on the best performance demonstrated in CESAR**
- **Published data by Knudsen et al. (2010)**
  - 7-8 to 4°C in delta T for the cross heat exchanger resulted in savings (compared to 3.7 GJ/ton CO_2 captured) in reboiler steam demand of 1-2% with MEA
  - No significant benefit of inter-cooling for MEA, but for CESAR 1 solvent up to 7% reduced reboiler steam demand
  - LVC, best benefit for MEA (20% reduced reboiler steam demand), somewhat less with CESAR 1 solvent
  - LVC means increased auxiliary power consumption
- **Basis for reference case in Octavius**
  - MEA with LVC, but not inter-cooling
  - Cesar 1 with both inter-cooling and LVC
  - Delta T of 5°C for the cross heat exchanger (specification)

Knudsen, J., Andersen, J., Jensen, J.N., and Biede, O. (2010), Evaluation of process upgrades and novel solvents for the post combustion CO_2 capture process in pilot-scale, presented at the GHGT-10 conference in Amsterdam

Reference case(s) for OCTAVIUS (2)

- **Other main specifications**

Parameter	**Fixed values**	**Comments**
Flue gas temperature after direct contact cooler (DCC)	40°C	Maybe further optimized
Capture rate	90 % of inlet content	Shall be obtained in all cases
Solvent systems	30 wt% MEA, Cesar 1(AMP+Piperazine)	
Packing material (included water-wash sections)	Sulzer Mellapak 2X	Might consider using a different packing for the stripper
Conditions of the CO_2 stream ready for transport	H_2O content: 50 ppmv Pressure: 110 bar Temperature: • • °C	
Amine/Ammonia content in flue gas leaving the absorber	<4.3 ppmv/6.9ppmv	

1st reference case for OCTAVIUS (1)

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- Upstream power plant
  - 800 MW_e bituminous coal case based on an advanced critical boiler an a steam turbine
- Solvent system: MEA
- Flowsheet modification: LVC
- Simulation tool for the capture plant: CO2SIM
- Optimization of reference case
  - Optimization with respect to minimizing capture cost using in-house code (SINTEF)
  - Variation of liquid flow-rate and LVC flash pressure
  - Other optimization parameters could have been e.g. packing height, pre-cooling temperature, reboiler temperature/pressure, but minor influence
  - System boundary:
    - Water-wash in absorber/stripper not included in simulations
    - CO_2 compression not included in simulations as reboiler temperature is kept constant at 120°C

1st reference case for OCTAVIUS (2)

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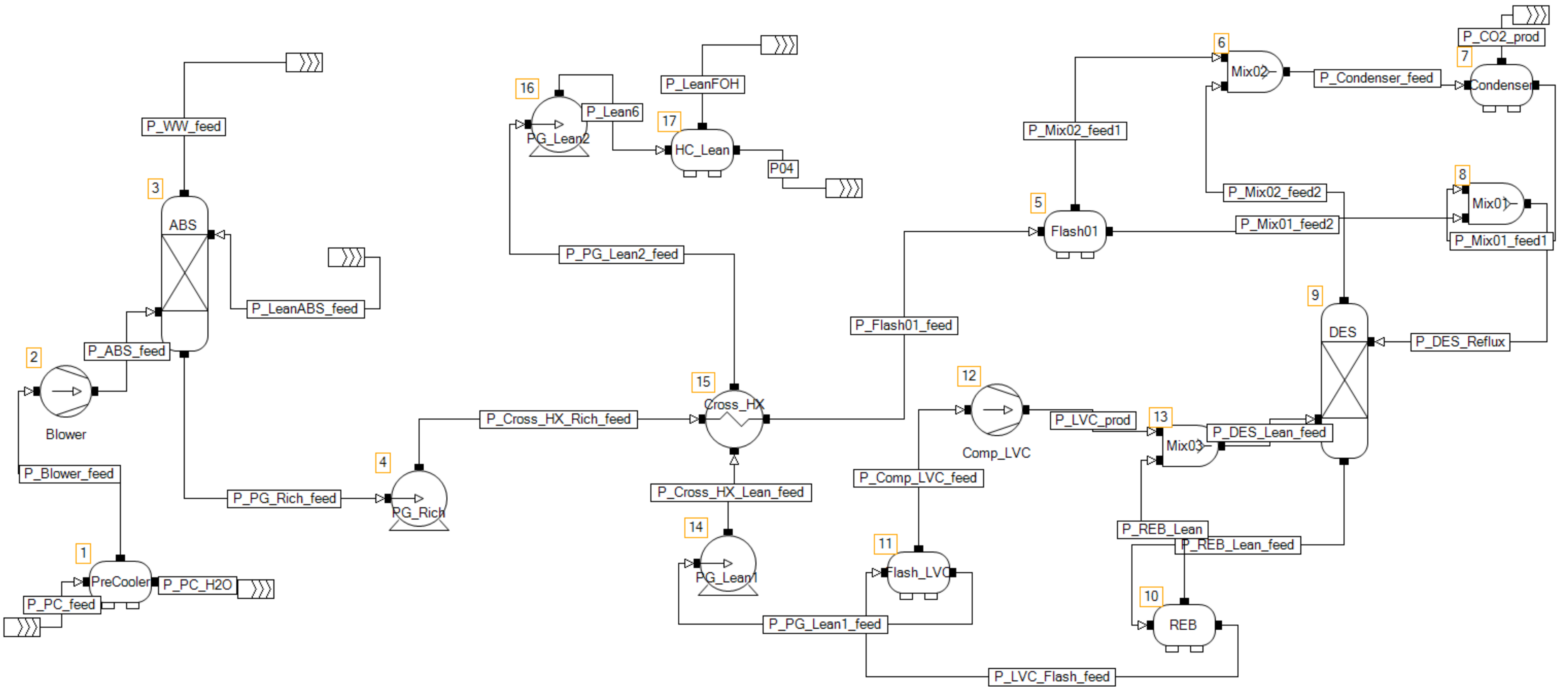
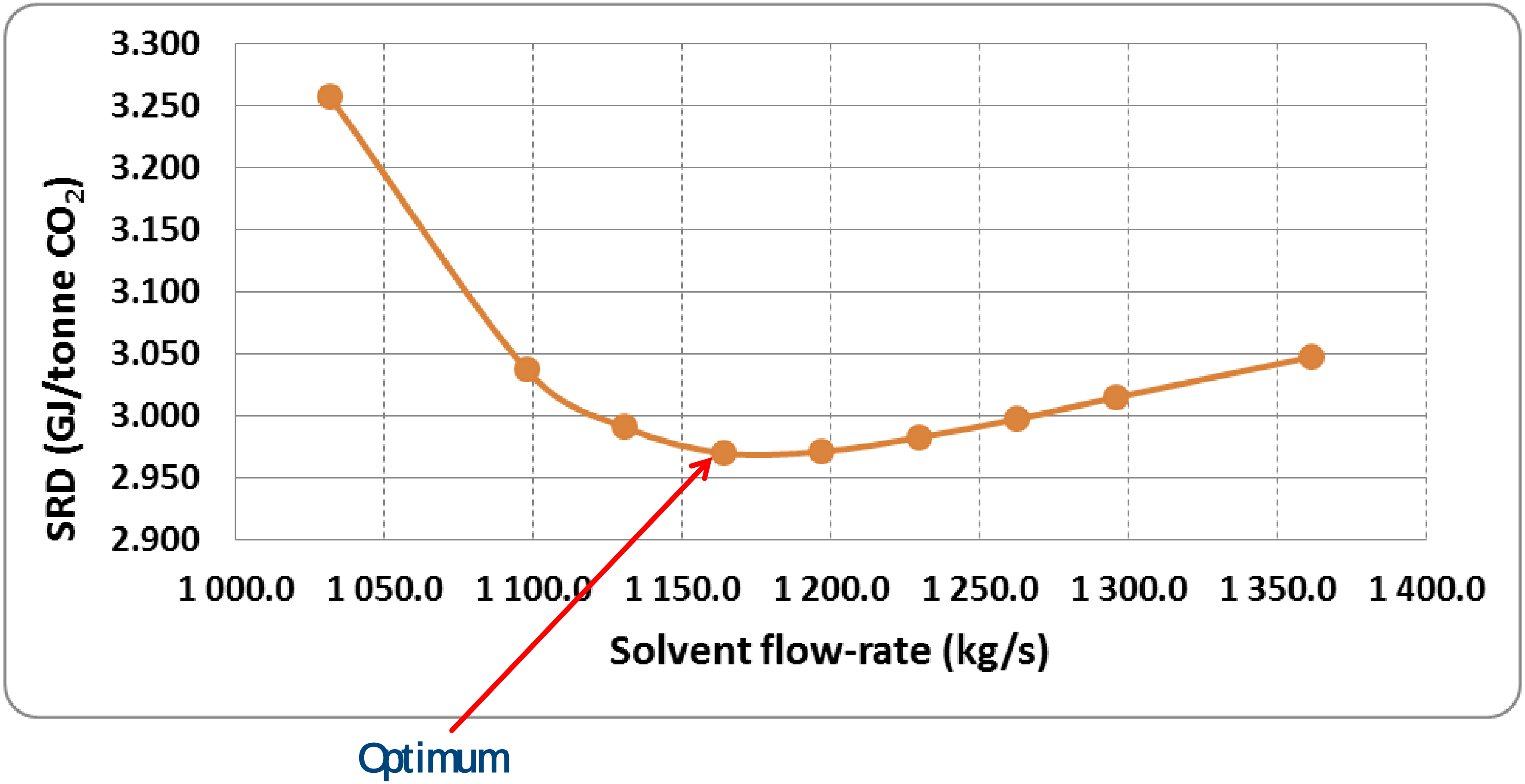


1st reference case for OCTAVIUS - Optimization of flow-rate

Specific Reboiler Duty (SRD) vs. Flow-rate – Flash pressure = 110 kPa



1st reference case for OCTAVIUS - Optimization of LVC pressure (1)

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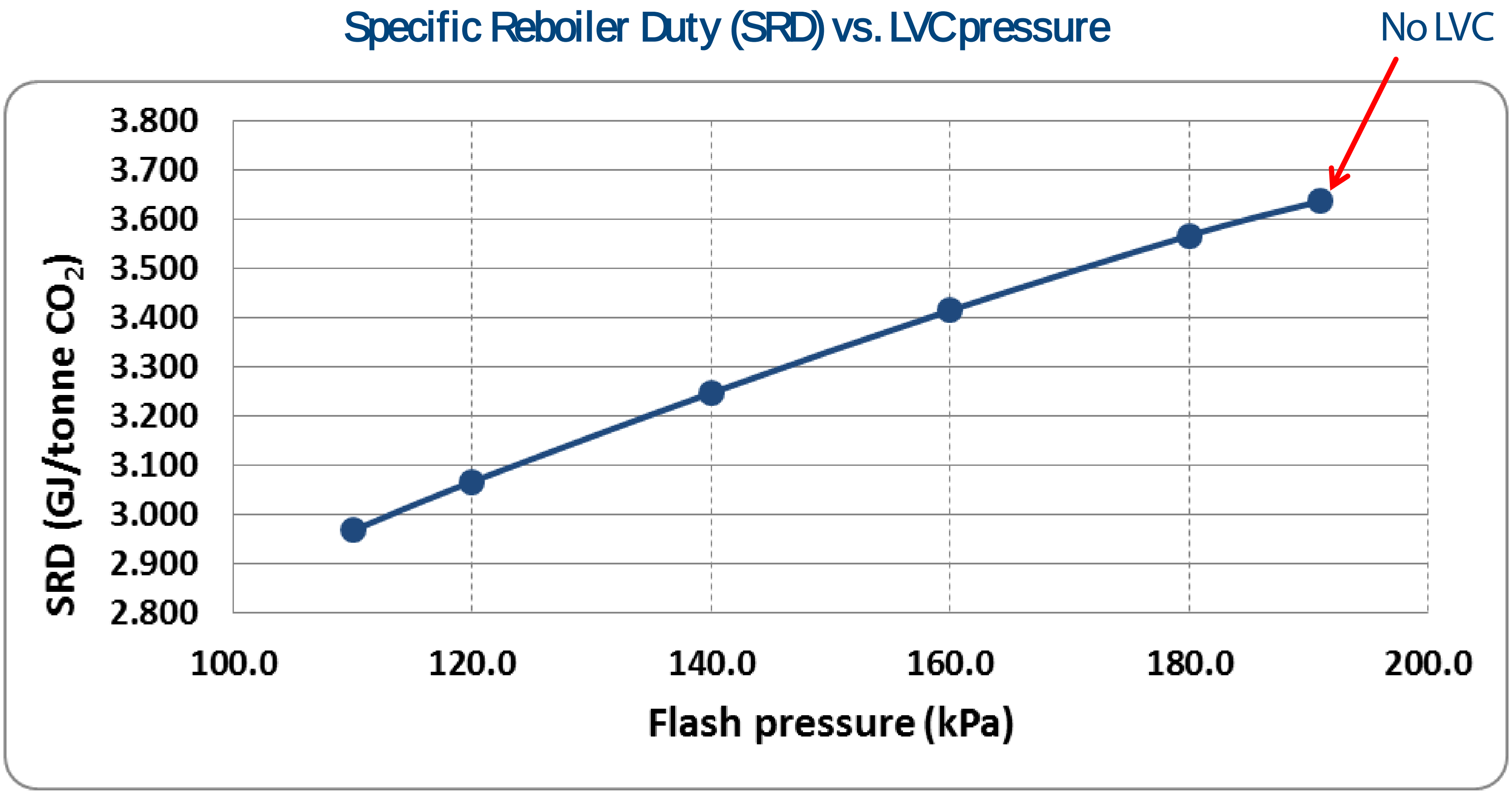

1st reference case for OCTAVIUS - Optimization of LVC pressure (2)

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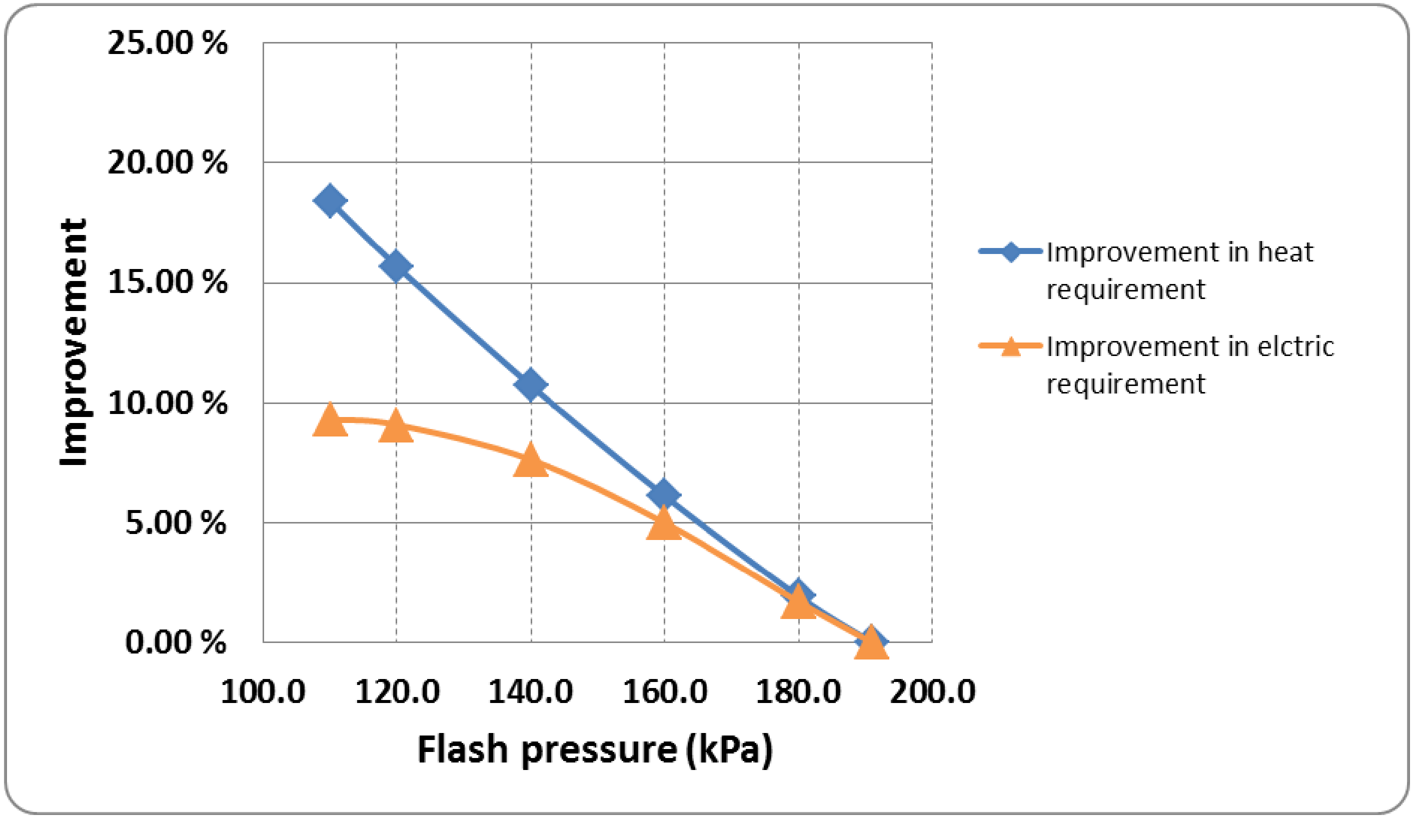
Improvement in heat requirement and effect in improved total electric requirement vs. LVC flash pressure



1st reference case for OCTAVIUS - Optimization of LVC pressure (3)

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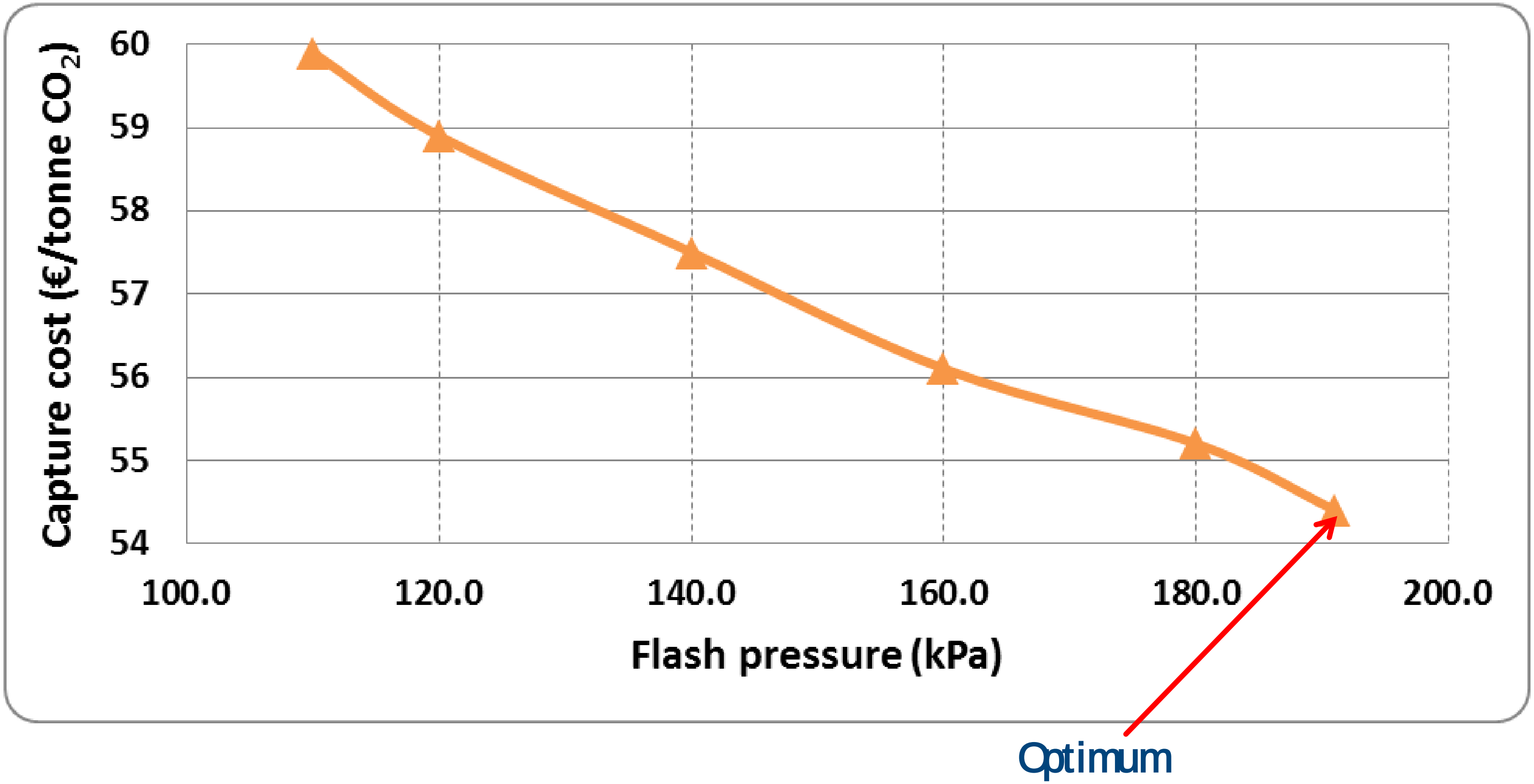
CO_2 capture cost vs. LVC flash pressure



Conclusion and further work reference cases in Octavius

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- Conclusions:
  - A methodology have been established to show improvements in OCTAVIUS compared to the Cesar project
  - One reference capture plant case is tried optimized, but cost-data must be further inspected
- Further work
  - Sensitivity in some cost-calculation parameters
  - Optimization of the three other reference cases (2 for each of the 2 power-plant cases)
  - Integration with power plant and cost calculation of overall plant (reference cases)

Acknowledgement

- This work has been performed within the FP7 project OCTAVIUS (Grant Agreement n° 295645).

- Partners involved in the work
  - TNO: Purvil Khakharia, Cristina Sanchez Sanchez
  - TUHH: Sören Ehlers, Ulrich Liebenthal
  - SINTEF: Geir Haugen, Actor Chikukwa
  - DTU: Philip Loldrup Fosbøl
  - E.ON: Laurence Robinson, Nick Booth
  - IFPEN: Adrien Gomez
  - EDF R&D: Fabrice Chopin