CONFIGURATION OF A FLEXIBLE AND EFFICIENT SCO2 CYCLE FOR FOSSIL POWER PLANT

3rd sCO2 European Conference

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 764690-

Why a flexible cycle for fossil plant ?

Needs

- Growing electricity demand
- Emergence of renewable energies
- Increasingly complex network management
- Electricity still predominantly fossil

- Hopes

- Reality
  - Future scenarios: fossil fuels will still remain important source

Project Objectives

- Design a more flexible and less environmentally damaging cycle
  - Take into account from the design stage the constraints due to flexibility

➡ Eliminate as much as possible future, costly modifications that penalize the plant's efficiency

  - Cycle with lower GHG emissions than the current cycle, less penalised if post-combustion CO2 capture

- Propose an innovative solution.
  - Reduction of the general environmental impact (less material, footprint.
  - Possibility of using other heat sources (solar, nuclear, biomass,...)

➡ Use a sCO2 cycle

Methodology

1st Step: Do not adapt the current steam cycles

=> Scientific literature and modelling of new cycle configurations with sCO2

2nd Step: Take into account flexibility constraints

=> Model future scenarios for the use of this type of power plant, which are more constraining than the current scenarios

3rd Step: Choose design to maintain correct cycle performance

=> Starting efficiency high enough to be able to integrate future constraints (new pollution control equipment, cO2 capture...)

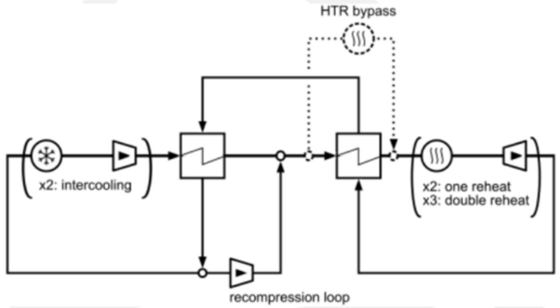
=> Easy to operate, not too complex design

1st Step : Define different cycle configurations

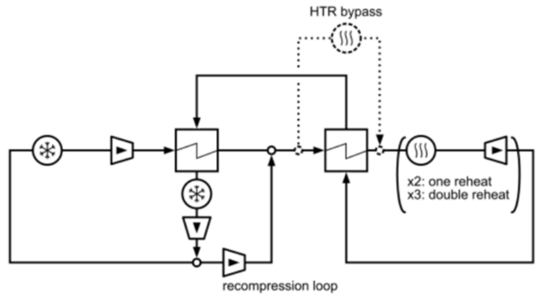
- More than 40 possible configurations in literature:
  - Must fit boiler constraints
    - low temperature of the working fluid at the boiler inlet
    - low pressure drops for high flow rate,
    - good heat integration for a high boiler efficiency...
  - Must be efficient and suitable for flexible operation loads

=> previous simulations (Mecheri & Le Moullec, 2016) and literature: reduction to 21 configurations, divided into 6 basic forms

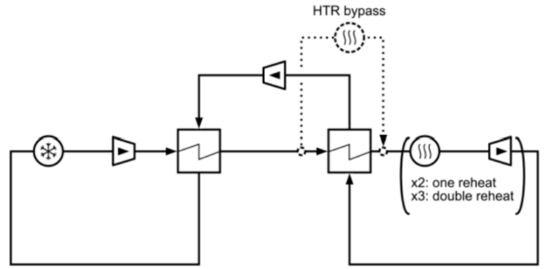
1st Step: Base Forms



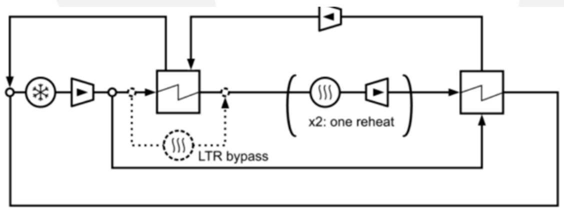
Recompression cycles



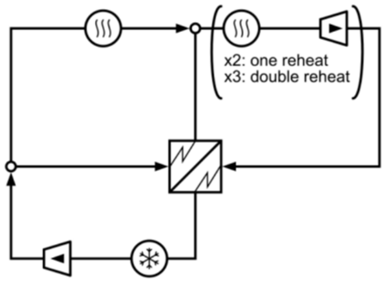
Partial cooling cycles



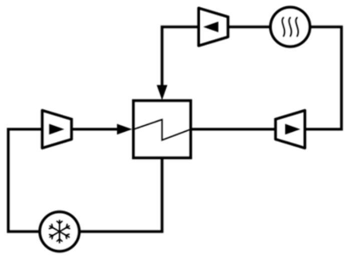
Pre-compression cycles



Turbine split flow cycles



Pre-heating cycles



Split expansion cycles

1st Step : Modelisation of the 21 cycles

sCO2flex

Fixed Parameters :

PARAMETER	UNIT	VALUE
Net cycle production	MWe	25
CO_2 temperature at the heat sink outlet (MSCUSXXT2)	°C	33
Maximum CO_2 temperature at the heater outlet (MSHSOXXT2)	°C	620
Maximum CO_2 pressure at the main compressor outlet (MSCOMXXP2)	MPa	25.0
Compressors isentropic efficiency	%	80
Turbine isentropic efficiency	%	90
Pressure drops in the heater (MSHSOXX)	MPa	No reheat: 0.25
		One reheat: 0.2 + 0.1
		Two reheats: 0.2+0.1+0.1
		HTR/LTR bypass : 0.1+0.2
Pressure drops in the recuperators (MSRCUXX)	% of inlet pressure	0.5
Pressure drops in the heat sink heat exchanger (MSCUSXX)	% of inlet pressure	0.5
Maximum number of intercooling	1	
Auxiliary consumption	MWe	-
Boiler maximal efficiency	%	94
CO_2 purity	%	100

Parameters for sensibility analyses:

MODIFIED PARAMETER	NEW VALUES
Heat exchanger and boiler pressure drops	HEx pressure drops = 0.1% of inlet pressure Boiler pressure drops = 0.1 MPa
Heat exchanger and boiler pressure drops	HEx pressure drops = 1% of inlet pressure Boiler pressure drops = 0.5 MPa
Boiler outlet maximal temperature	550°C (with compressor outlet pressure = 20 MPa)
Boiler outlet maximal temperature	700°C (with compressor outlet pressure = 30 MPa)
CO_2 minimal temperature (cooling temperature)	30°C
CO_2 minimal temperature (cooling temperature)	34°C

Modelisations of all the cycles with Aspen

1st Step: results of modelisations

Modelisations results:

- Effect of reheating: CO_2 mass flow reduced when cycle efficiency increases
- Effect of intercooling: slightly increase the cycle efficiency while ensuring at slightly lower CO_2 temperature at the boiler inlet.
- Effect of bypassing the recuperator: minor impact on the cycle performance and enables to reduce the minimal CO_2 temperature at the boiler inlet

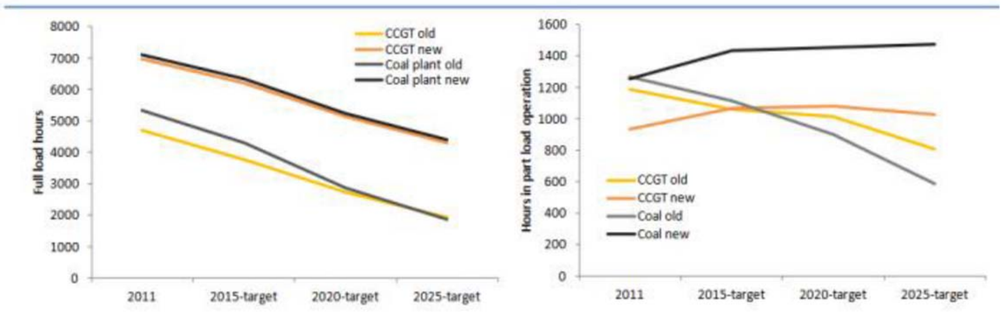
Main sensibility analysis results:

- Cycle pressure drops, and boiler outlet temperature have high impact on the cycle efficiency
- Cooling temperature and main compressor outlet pressure have lower impact of the cycle performance
- Cycle temperature balance impacted by the pressure drops
- Cooling temperature variation study shows that the cycle performance will be affected by variability on the cooling temperature (flexibility)

2nd Step : Modelisation of future use of the plant

Study of the different energy mix scenarios:

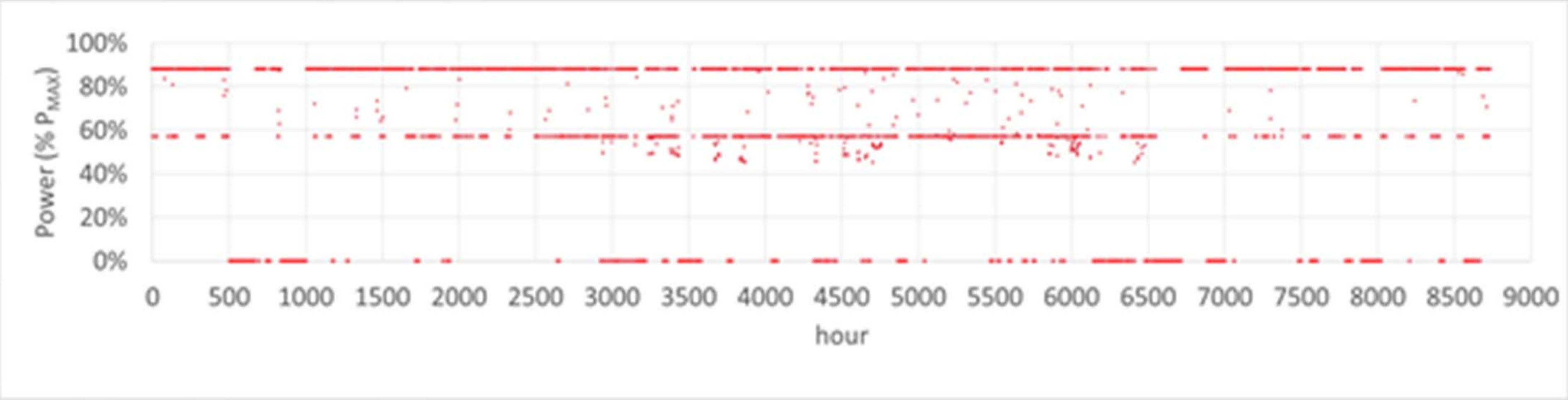
- EU Reference Scenario: in phase with the European energy and environmental targets
    - 50% of renewable energy in the electricity mix
    - + 27% of energy performance
- IEA analysis



Source: IEA analysis.

2nd Step: Modelisation of future use of the plant

Modelisation with EDF software : 2030 Plant operation



2nd Step: Flexibility constraints

sCO2 boiler:

- Most of the current steam boiler constraints are expected
- Combustion should still be the same
- Global geometry is not expected to be completely different from current technologies
- Only the working fluid is changed

sCO2 turbine:

- More compact than current steam turbines => problems related to thermal expansion will be different
    - Limitation of the differential expansion,
    - Increased impact of leakage losses on turbine efficiency possible

3rd Step : Final configurations choice

Constraints related to the project sCO2-Flex objectives:

- Performance
  - Most efficient cycles: recompression cycles
  - Most pejorative cycles: double reheat cycles
    - more complex and challenging for the turbomachines
    - Boiler CO_2 temperature about 540°C, higher than 470°C and not recommended for boiler integrity
- Flexibility and the control of the cycle
  - Complex and multipart cycle architectures can be difficult to control and regulate.
  - Simple cycle architecture privileged

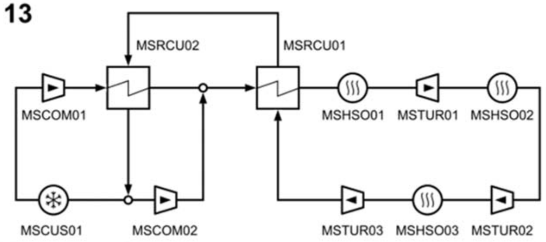
3rd Step : Final configurations choice

Constraints related to the components:

- Boiler
  - Integrity depends on cooling capacity of the working fluid (CO_2 in our case) to protect the boiler tubes and wall surfaces.
  - CO_2 temperature in the boiler must be securely and accurately controlled to ensure material protection
- Turbomachinery
  - Design of turbomachines changes when cycle architecture changed (size, rotation speed, number of stages…)
  - Mechanical and manufacturing point of view: Pre-compression cycles are more suitable

Conclusion : 3 cycle configurations

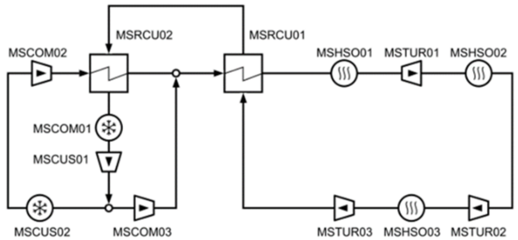
13



For performance:

Recompression cycle with double reheat

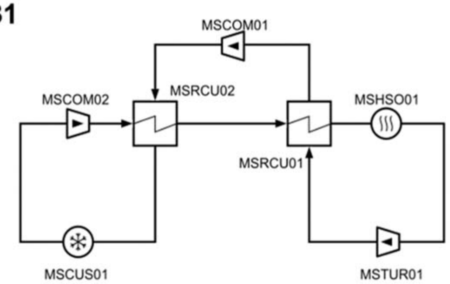
23



For components integrity:

Partial cooling cycle with double reheat

31



For Simplicity:

Pre-compression cycle

Conclusion

Main objective of the study:

Find several configurations of supercritical CO2 cycles that would offer a compromise between performance and flexibility

Difficulty:

Break free from the habits associated with conventional steam and water cycles

- Identification and modelisation of 21 cycles configurations
- New annual reports on operation of thermal plant
- Operating and components experts review to choose the most interesting cycles

Perspectives:

Optimize the most interesting configuration according to developments of turbomachines, exchangers, boiler as well as the optimization of the control system.

CAGNAC Albannie

albannie.cagnac-1@edf.fr

MECHERI Mounir

BEDOGNI Stefano

EDF R&D