A sensitivity analysis of a Cryogenic Carbon Capture System on a LNG ship engine

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Introduction

Maritime shipping weighs for 3% of global CO_2 emissions [1]. Cryogenic Carbon Capture (CCC) systems are considered a great transitional technology [2][3][4] along MonoEthanolAmine (MEA) solutions. IMO recommending the use of LNG powered ships looking ahead to 2040 [5], CCC unlock their full on-board potential :

- CCC consumes five time less energy than MEA [6]
- Maximum capture rate is 73% without any added power using MEA [7]
- To achieve 90% CO2 capture rate, fuel overconsumption is 17 - 24%, and added power is 60 – 64 % (Main engine) to 79 - 88% (all engines) [3]

Coupling to engines are still insufficient, TRLs are still low [8] and large-scale on-board performances do not meet laboratory ones: to rocket on-board CCC, improvements on coupling capture to ship engine are mandatory.

Numerical model

Simulations run on Simcenter AmeSim and engine is a software example from GTPower. LNG is both fuel and the only cold source on-board.

- Heat exchangers are designed for a specific case using NTU method.
- Compressors efficiencies are 0.7.
- Molecular sieve sorption enthalpy is 2.43 MJ/kgH2O.

Method

Sensitivity analysis are conducted over Excess air ratio, Engine Load, Gas Treatment Ratio and Operating Pressure. Base case is :

$$\lambda = 1.6, \quad Load = 75\%, \quad Gtr = 0.282, \quad P = 4.2\ bar$$

Powers are converted using numerical electrical machine with efficiencies :

$$\eta_{alt} = 0.95, \quad \eta_{meca\ pump} = 0.95, \quad \eta_{eng\ elec} = 0.99, \quad \eta_{heater} = 1$$

Fig 2 : LNG Engine data

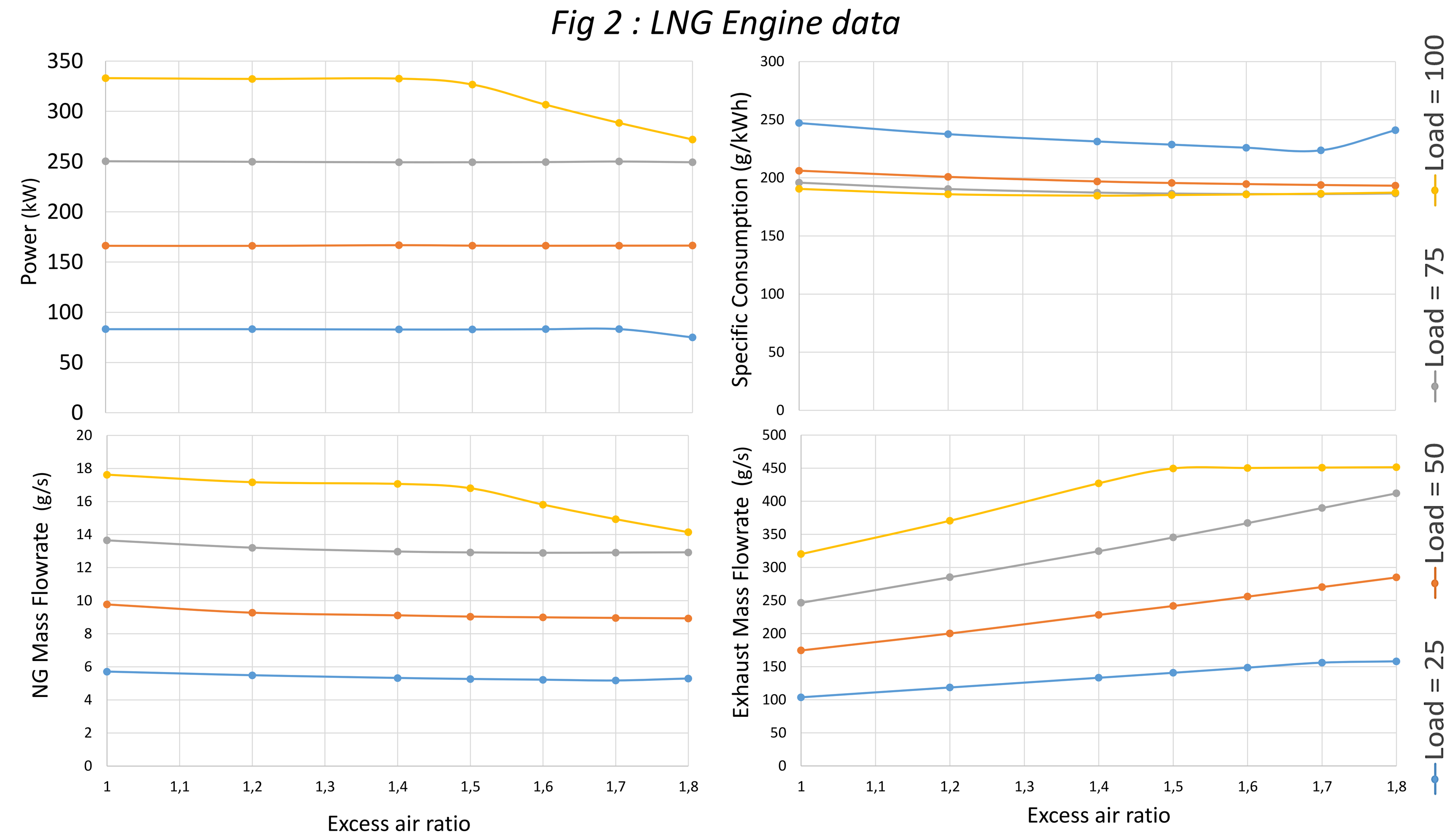
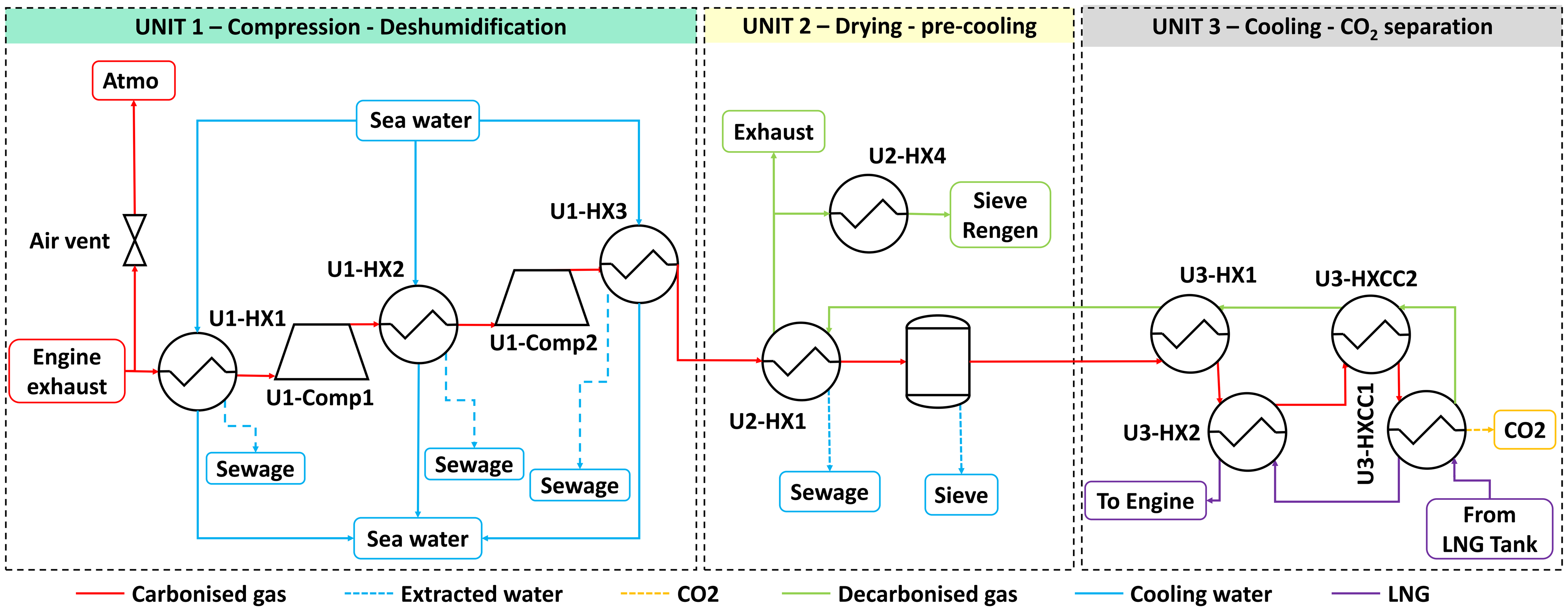


Fig 1 : Cryogenic Carbon Capture System Model



- $P_{elec,H} = \frac{P_{heat}}{\eta_{heater}}$
- $P_{elec,C} = \frac{\omega_{comp} \mathrm{T}_{comp}}{\eta_{eng\ elec}}$
- $P_{elec,HX} = \frac{q_v \Delta p}{\eta_{meca\ pump} \eta_{eng\ elec}}$
- $P_{gross} = \eta_{alt} P_{brake}$
- $P_{cons} = \sum_{consumers} P_{elec,consumers}$
- $\mathrm{CR} = \frac{\dot{m}_{capture}}{\dot{m}_{CO_2,exhaust\ eng}}$
- $E_{pen} = \frac{P_{cons}}{\dot{m}_{capture}}$

Sensitivity analysis

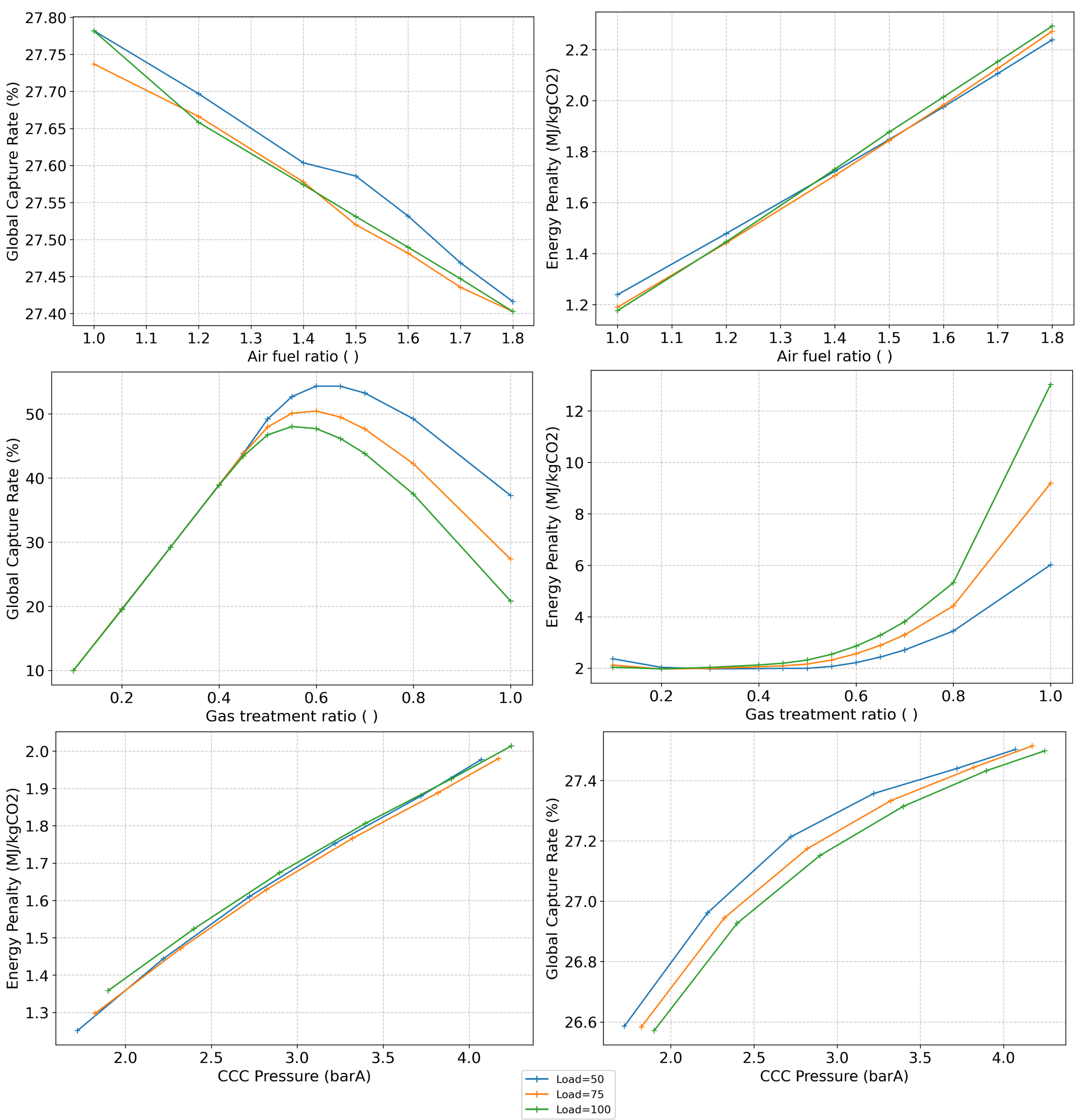


Fig 3 : Excess air ratio, Gas treatment ratio and Operating pressure influence on Capture rate and Energy penalty for different Engine load

Discussions and conclusions

Compressors are the main energy expense. LNG as fuel and only cold source is unable to generate enough cold power at high Excess air ratio and Gas treatment ratios.

The treated gas flowrate highly influences captures performances, until it becomes impossible. Excess air ratio and Gas treatment ratio strongly influence CCC performances, through composition and mass flow rate alteration. Load sensitively affects capture rates, but is tackled by system resilience. Despites, the added energy requirement damages available power and specific fuel consumption. The lower the Operating pressure, the better the performances. However, High pressures generate more hydraulic power from the exhaust gases, which could be used by a power supply device.

Performance presents an optimal gas treatment ratio. Adjusting Gas treatment ratio to accommodate multiple defined operating points would allow handling the full engine operating range.

Perspectives

- Exploring capture at atmospheric pressure or before engine turbine, to balance with CO2 conditioning duty.
- Improving cold power use.
- Strengthening the coupling with the combustion engine.

References

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