Towards Highly-Flexible Carbon-Clean Power Production using Gas Turbines:

Exhaust Gas Recirculation and Cycle Humidification

Ward De Paepe, Homam Nikpey, Simone Giorgetti, Marina Montero Carrero, Mohammad Mansouri, Svend Bram, Laurent Bricteux, Alessandro Parente, Francesco Contino

University of Mons & University of Stavanger & Université Libre de Bruxelles & Vrije Universiteit Brussel

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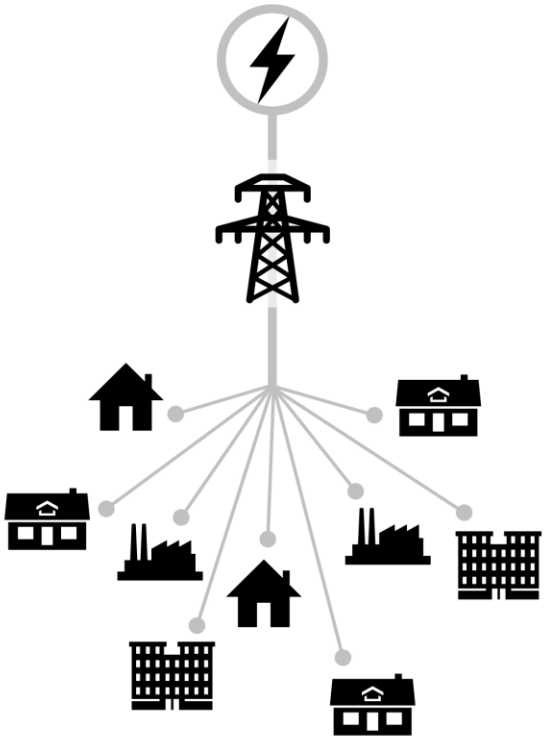
Gas Turbines have their place in future energy production.



Centralised system

To get a place in the future energy production, the Gas Turbine needs to evolve.

The GT has to become more efficient

both at full and part load operation

The GT has to become fully CO_2 neutral/negative

by using biofuel/bio-energy

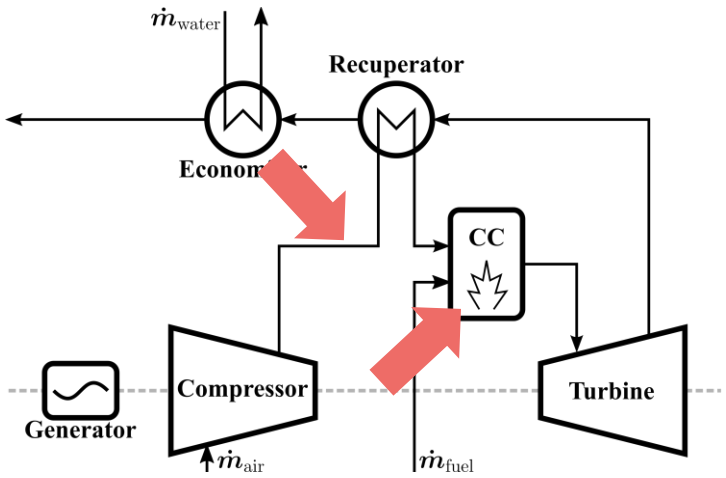
by performing CCUS

The GT has to become MORE flexible

flexible in terms of fuel and operation

➔ **Cycle humidification offers an opportunity.**

Cycle humidification improves the electrical performance of the GT



Humidification aims at reducing the compressor work

higher turbine mass flow rate

Humidification leads to higher specific power and electrical efficiency

Possibility for waste heat recovery

Positive side effect: lower NO_x emissions

Especially HAT cycle has high potential

➔ The flue gases still contain CO_2

Exhaust Gas Recirculation helps reducing post-combustion carbon capture penalty

CO_2 content in the exhaust gases is low, resulting in a high CC penalty

Flue gases still contain large part of O_2

due to large excess of air

Exhaust Gas Recirculation (EGR) offers a solution

by increasing the CO_2 content of the flue gases

by reducing the flue gas flow rate

NO_x emissions are reduced

➔ **EGR has a negative impact on the cycle efficiency**

Humidification in combination with EGR allows highly-flexible carbon clean power production

Cycle humidification increases the flexibility and the efficiency

but still CO_2 emissions.

EGR reduces the carbon capture penalty

but has a negative impact on efficiency.

Combining cycle humidification with EGR is a promising solution.

There is a strong need for more advanced numerical models and experimental validation.

2 different models simulating a humidified mGT with EGR have been developed and validated experimentally.

Apply these **concepts** first on **small-scale applications (mGT)**.

Two different models have been developed: **IPSEpro and Aspen**

Both models simulate **mHAT cycle with EGR**

Experimental validation of the humidified cycle and EGR

Aim: **validated models** to get more insight on the more advanced cycles

Micro gas turbine cycle humidification with EGR for highly-flexible carbon-clean power production

System modelling

Numerical model comparison

Experimental validation

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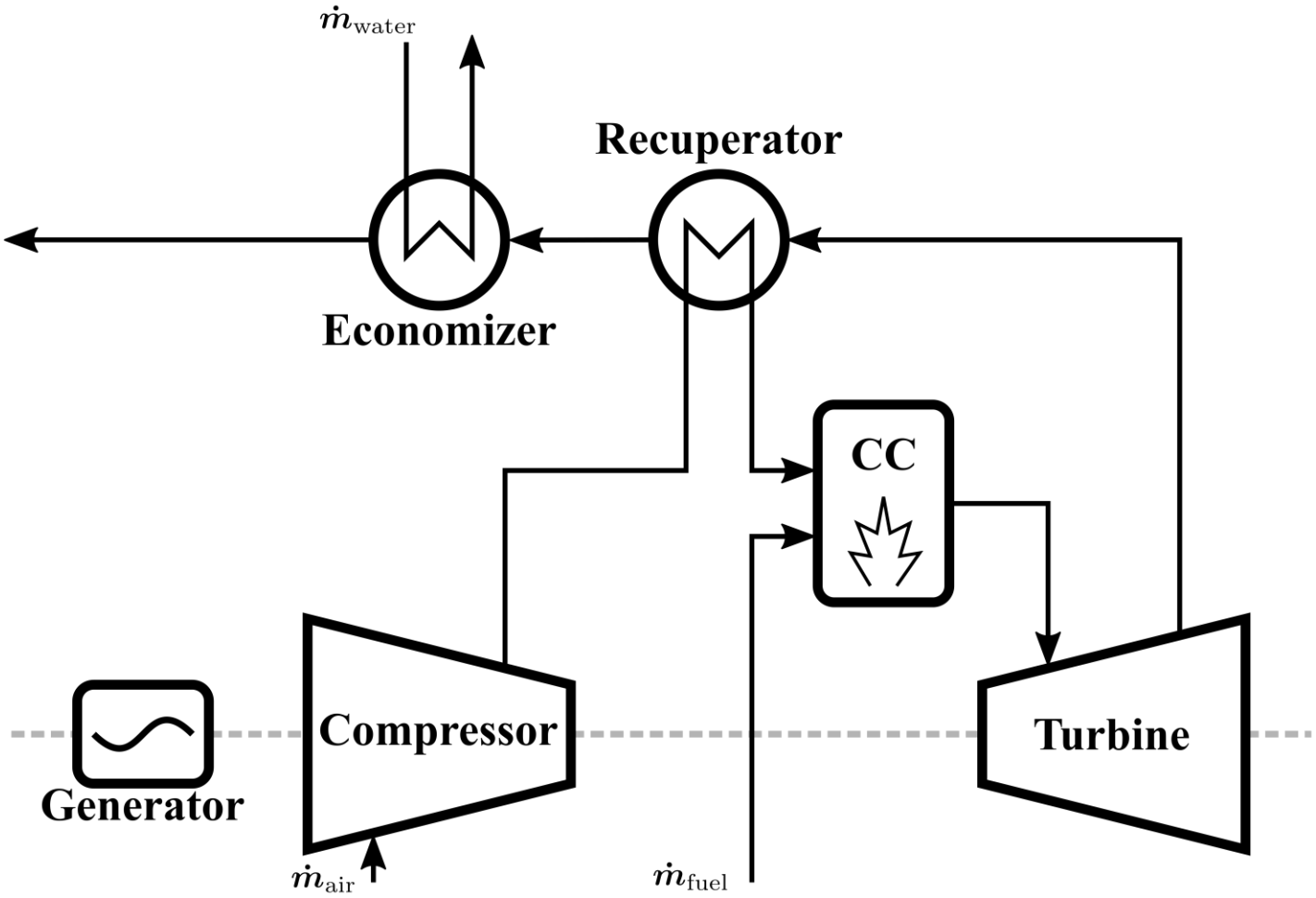
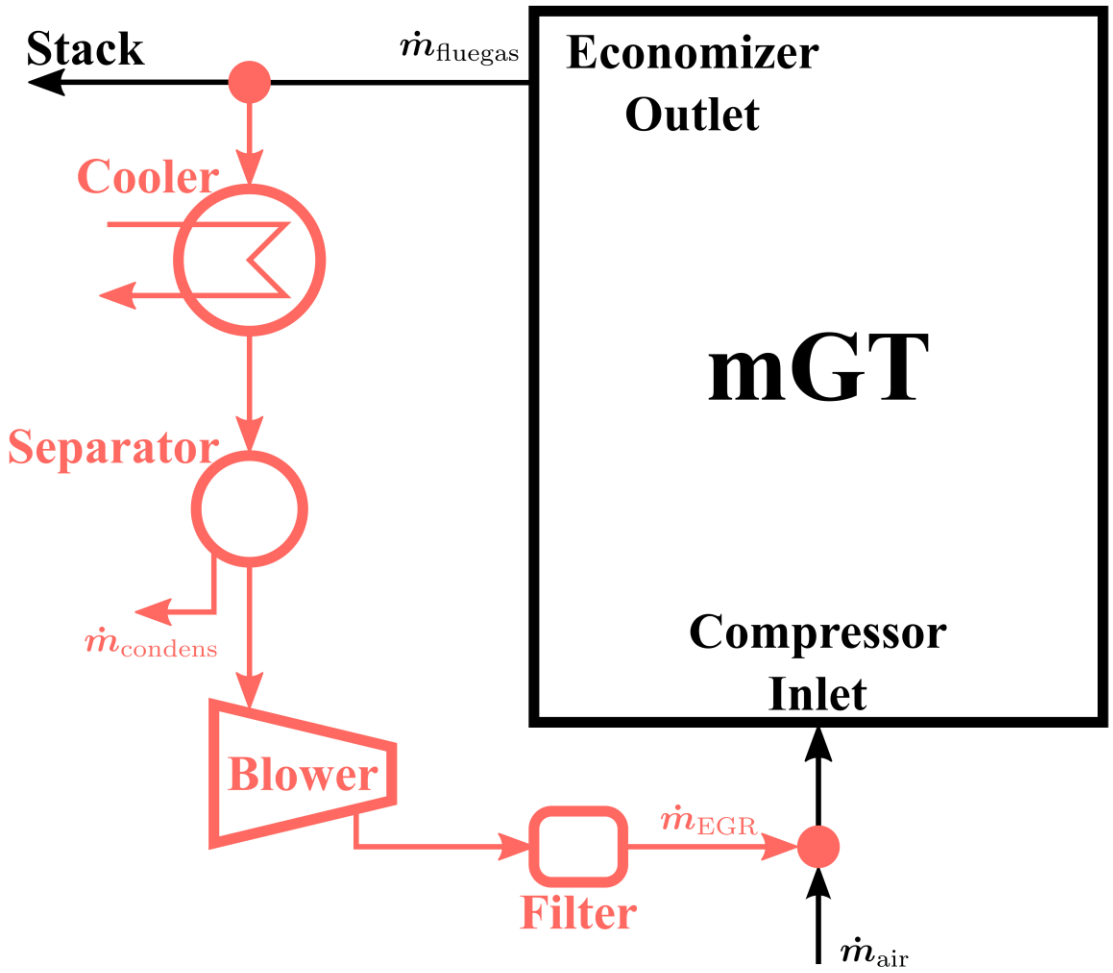
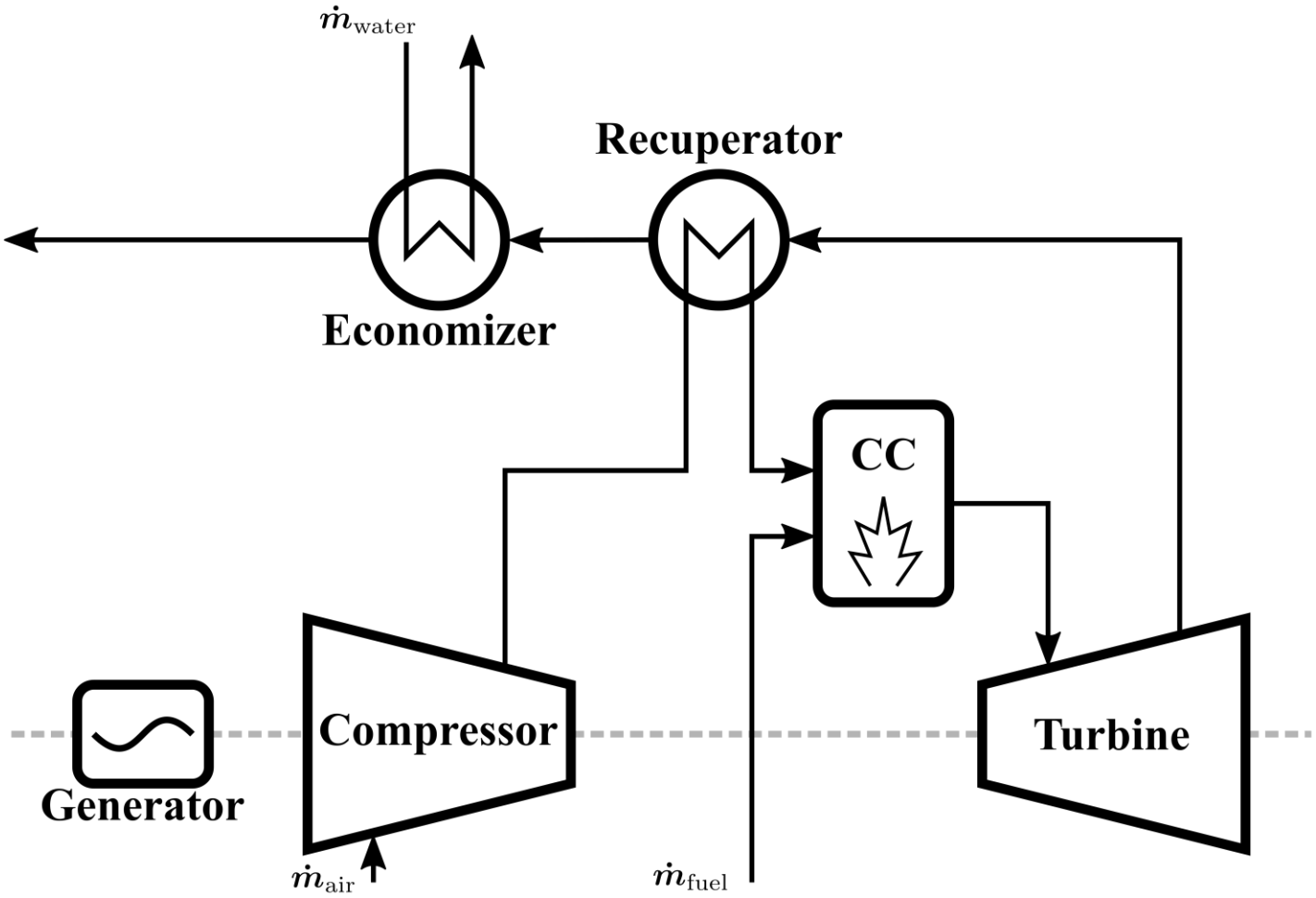
Numerical models based on the Turbec T100 micro Gas Turbine.



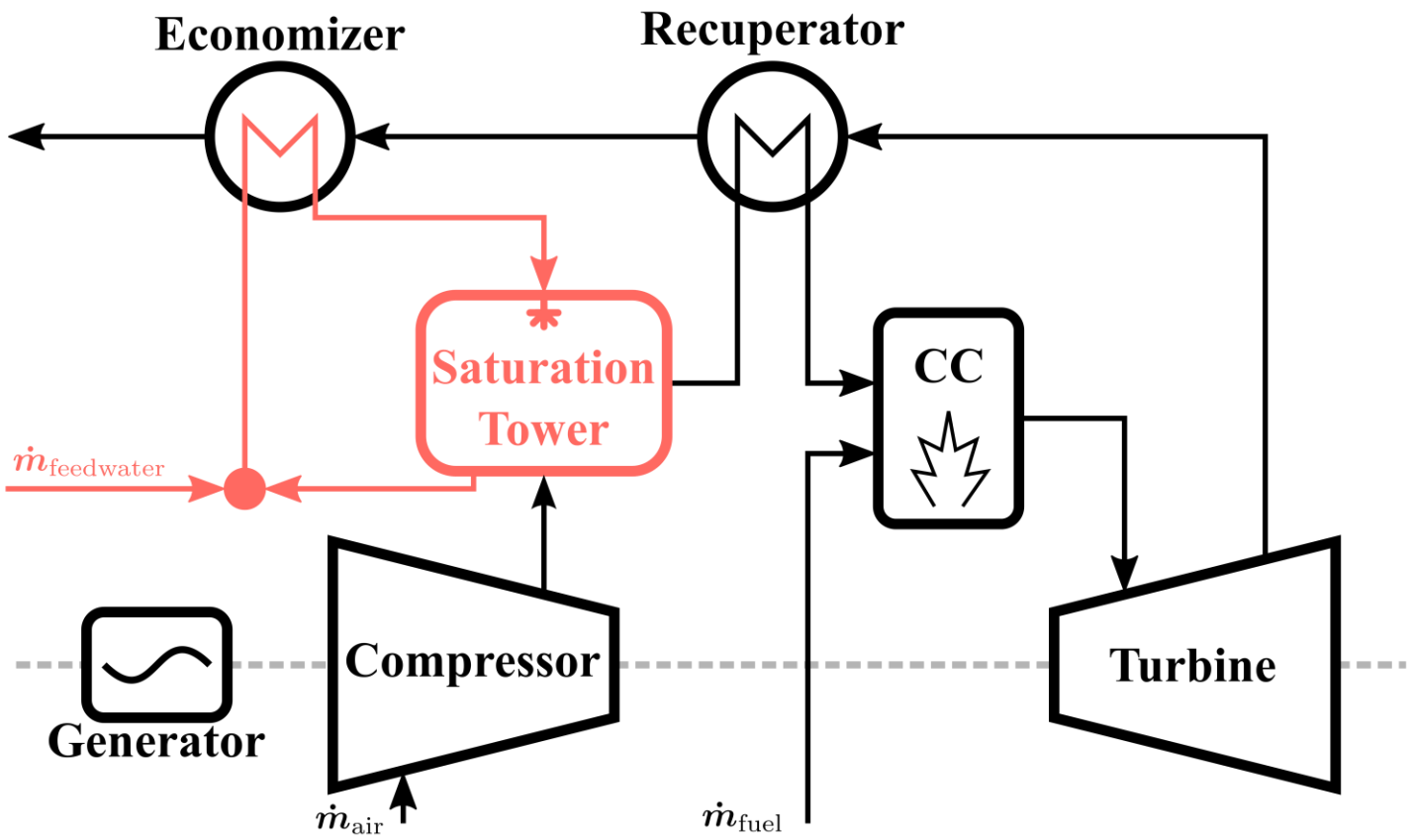
An EGR loop is added to the mGT cycle to increase the CO2 content of the flue gas.



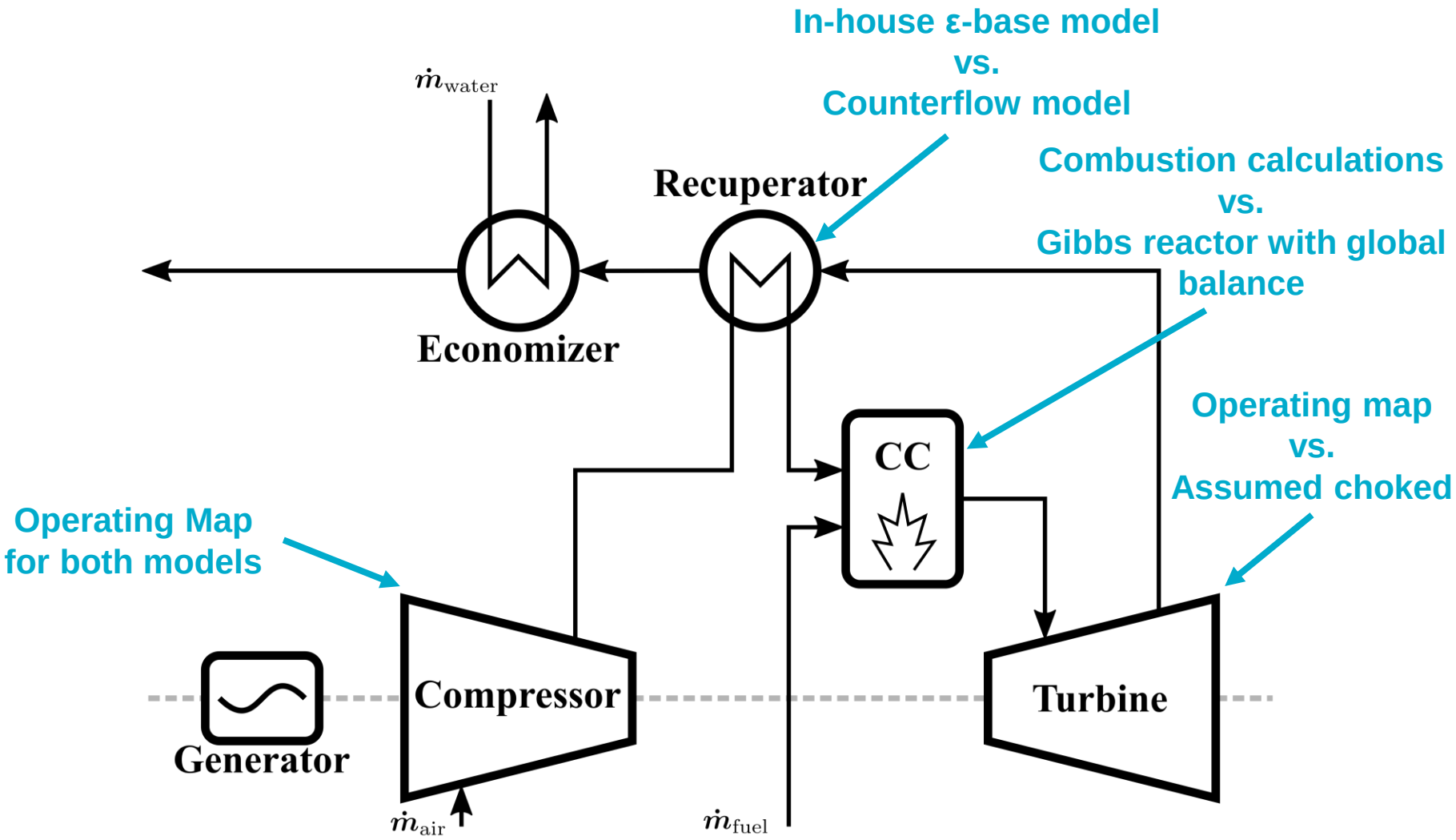
As humidified mGT, the micro Humid Air Turbine or mHAT was selected.



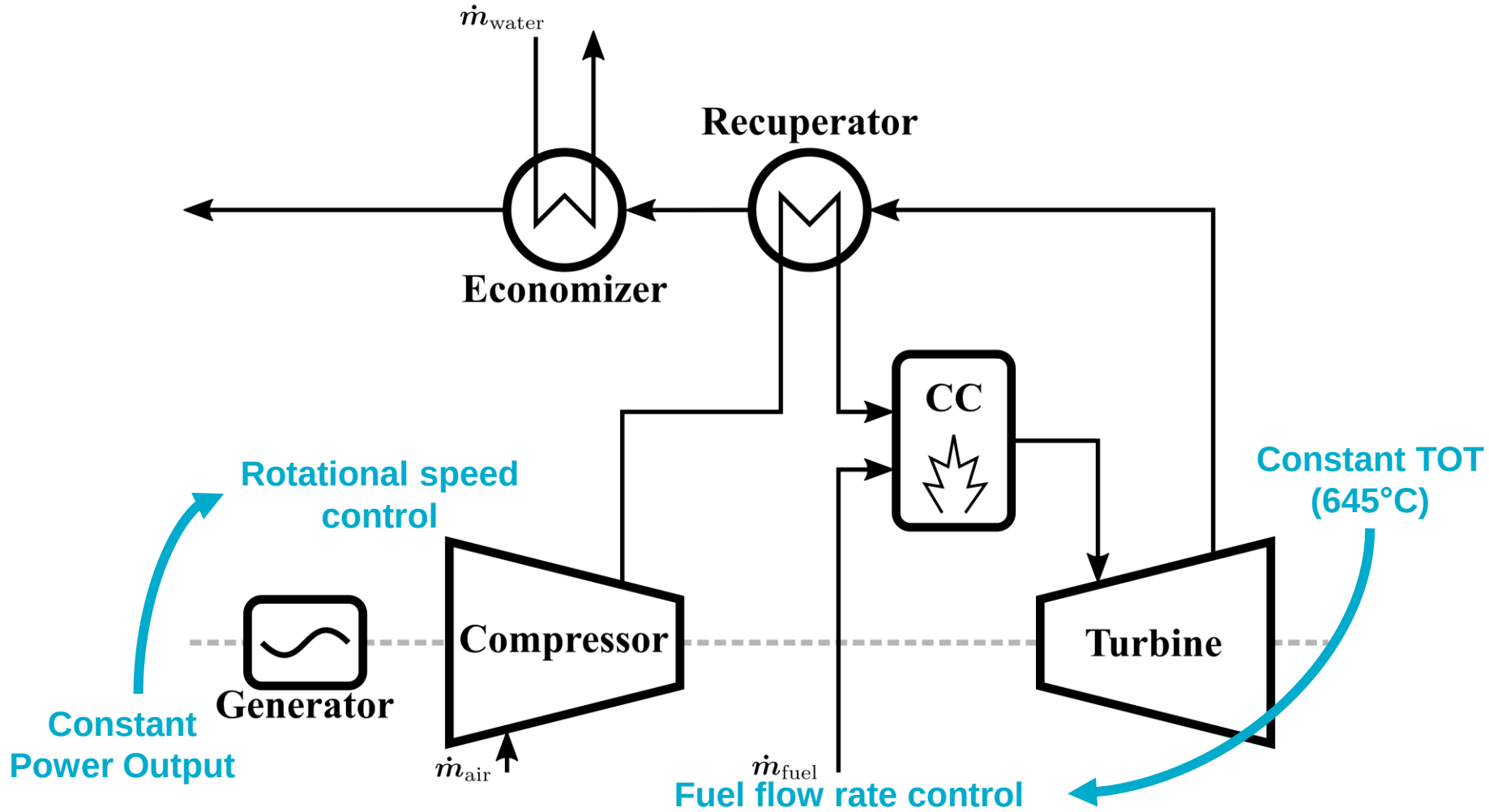
The mGT is converted into a mHAT
by adding a saturation tower to the cycle.



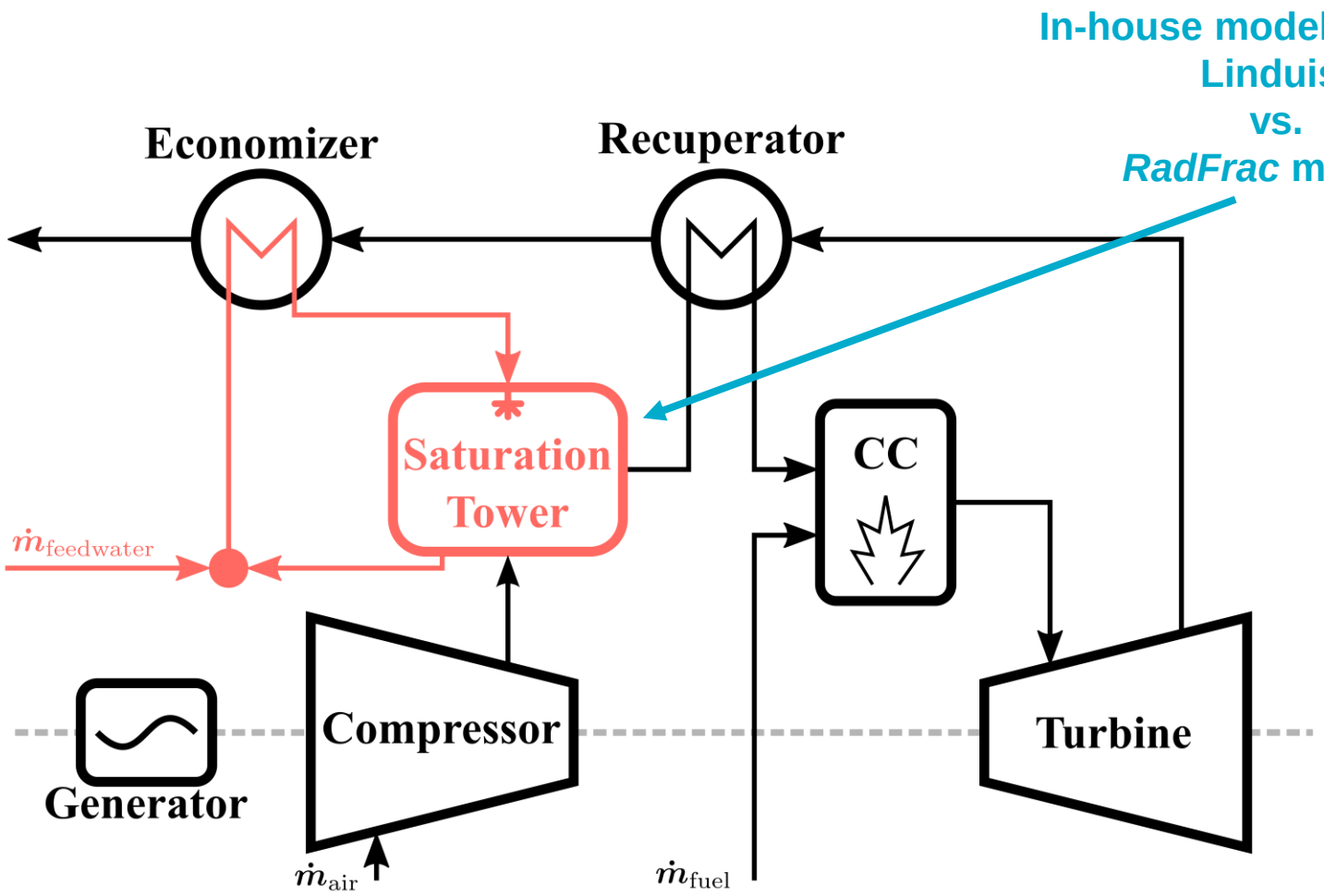
The different components were modelled is a similar way in both models.



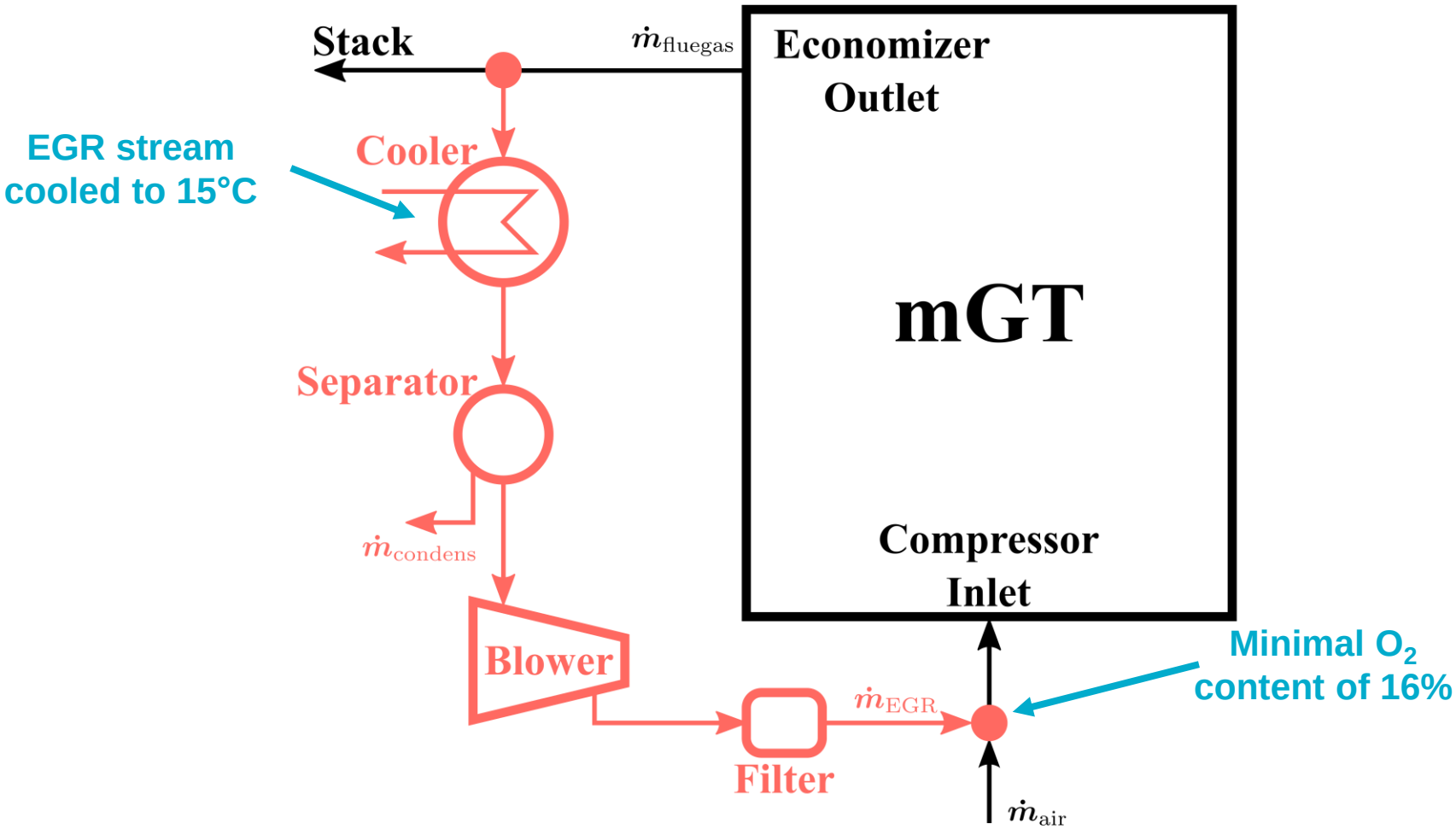
The standard T100 control system was implemented in both models.



Cycle humidification was modelled in a similar way in both models.



Several assumptions were used during the EGR simulations.



Micro gas turbine cycle humidification with EGR for highly-flexible carbon-clean power production

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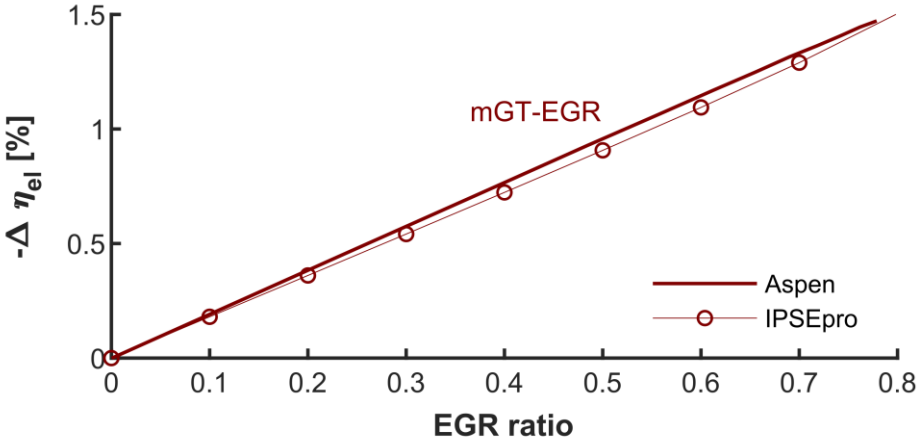
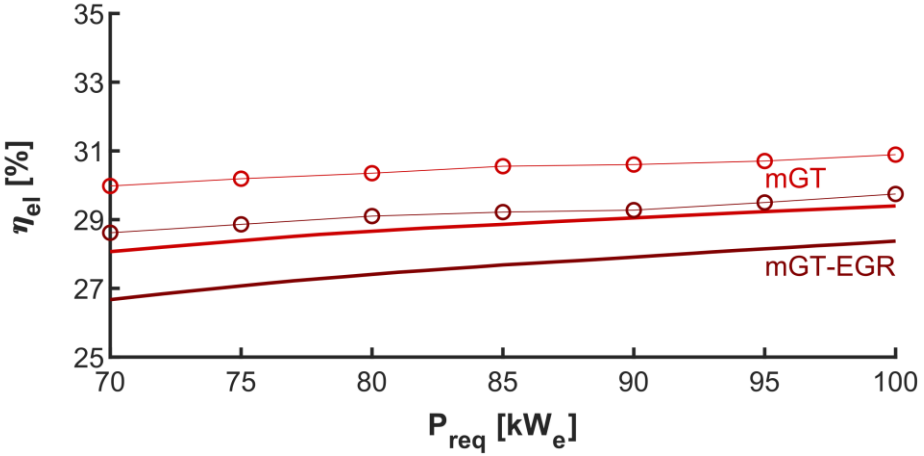
Model comparison of the IPSEpro and Aspen model show good agreement for dry EGR simulations.

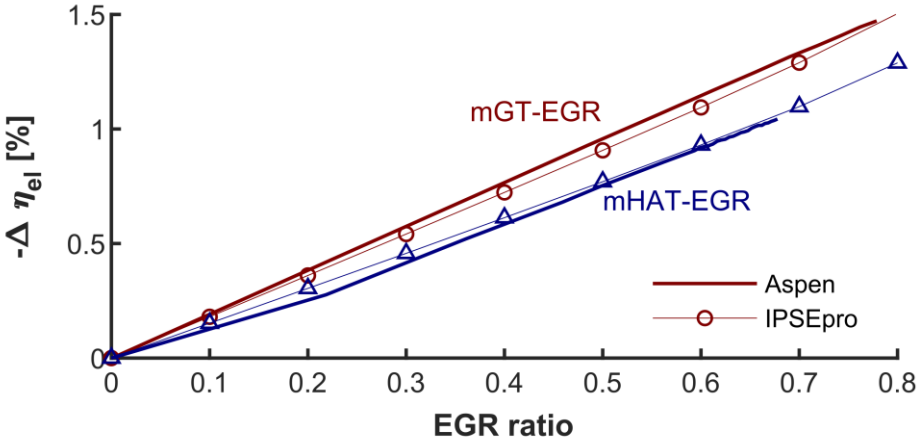


Good agreement for the energy penalty prediction at increasing EGR ratio.

Moderate agreement for absolute efficiency prediction due to different model tuning

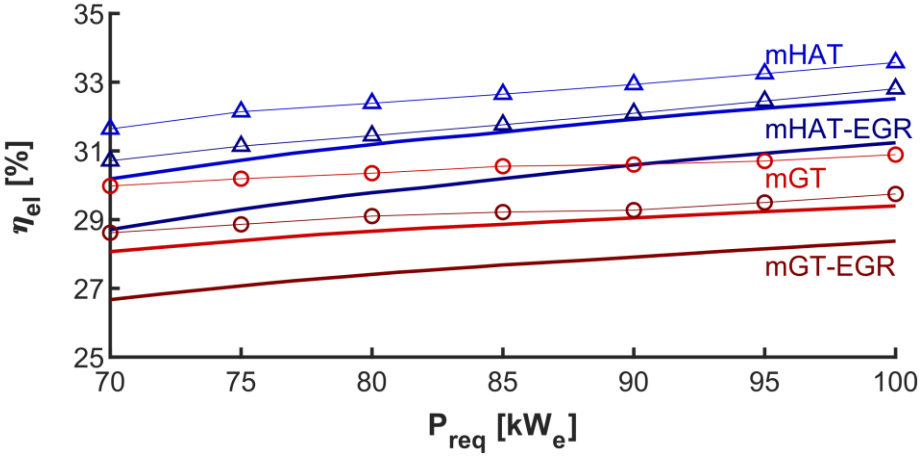


Both models predict similar behavior when applying humidification to the cycle.

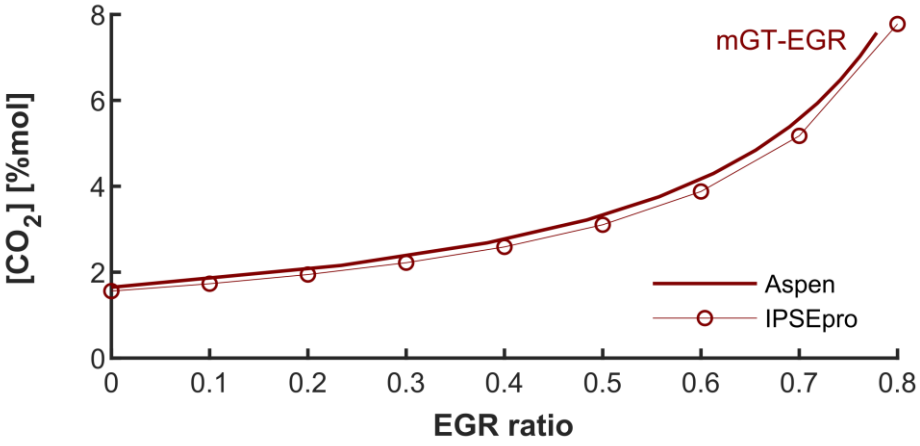


The energy penalty is reduced when humidifying the cycle.

Cycle humidification (even with EGR) results in higher efficiency than the dry mGT

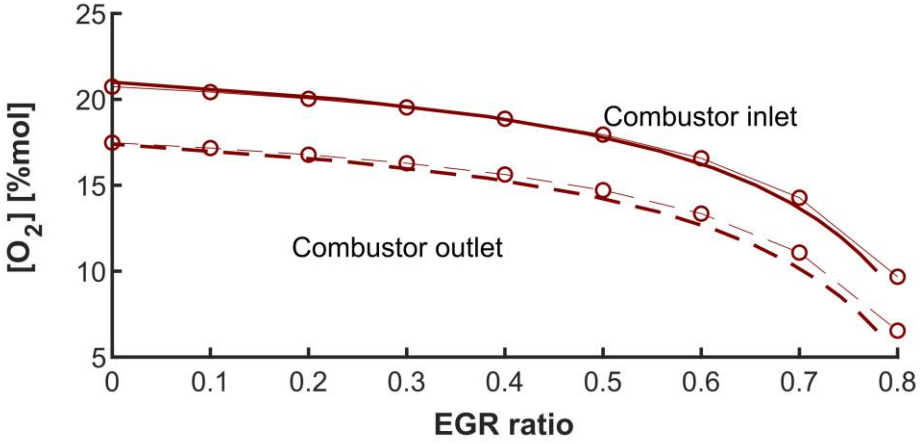


Controlling the EGR rate, allows to control the flue gas composition.



CO_2 concentration increase with increasing EGR ratio.

The amount of O_2 entering the combustion chamber reduce with increasing EGR rate.



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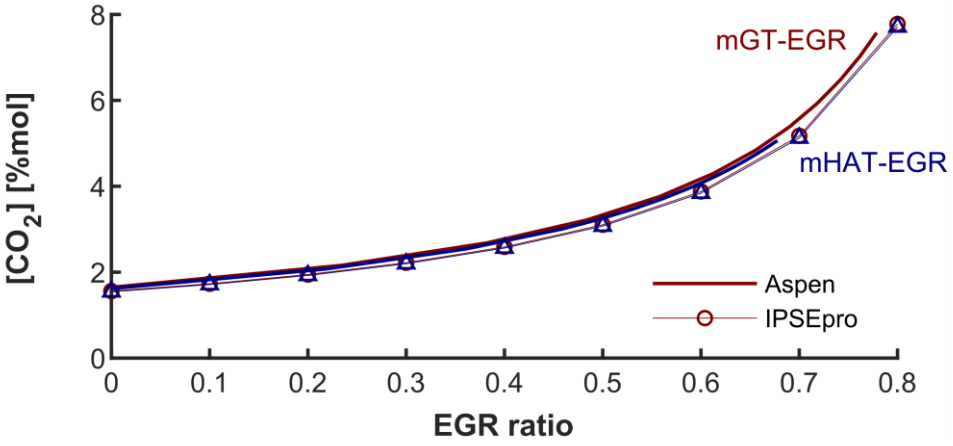
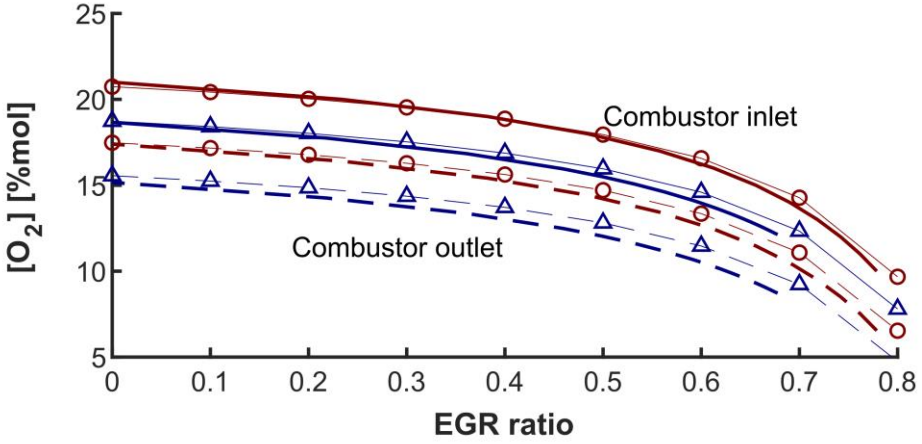
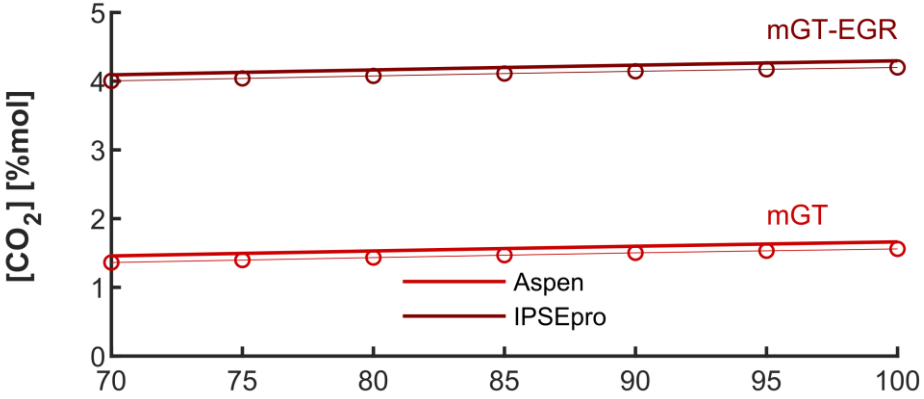


CO_2 concentration is similar for both the wet and dry case.

The amount of O_2 entering the combustion chamber is significantly lower in the wet case.

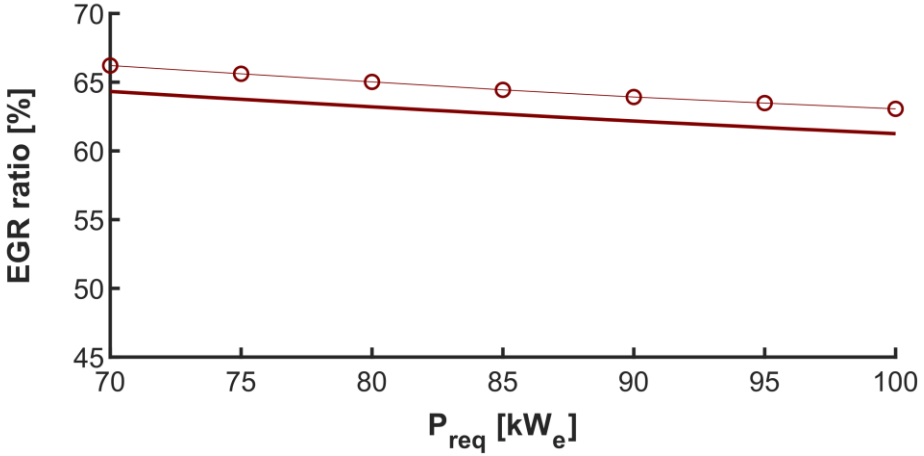


The final CO_2 concentration that can be reached is independent of the power output.



CO_2 concentration remains constant when changing power.

The EGR ratio increase with decreasing power output.



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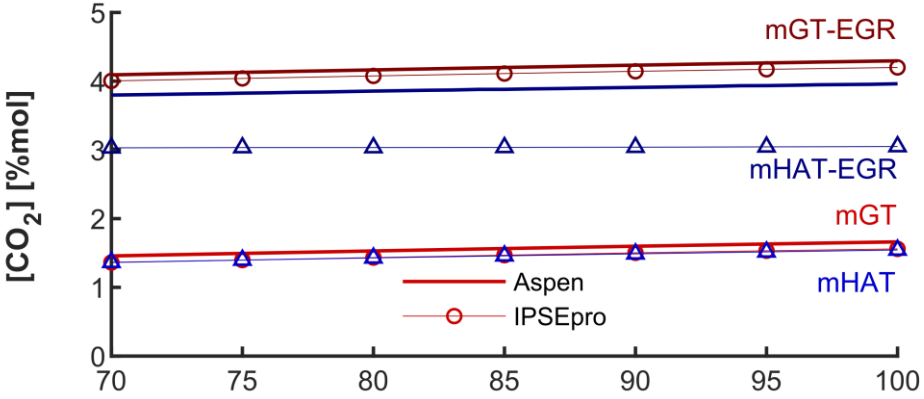
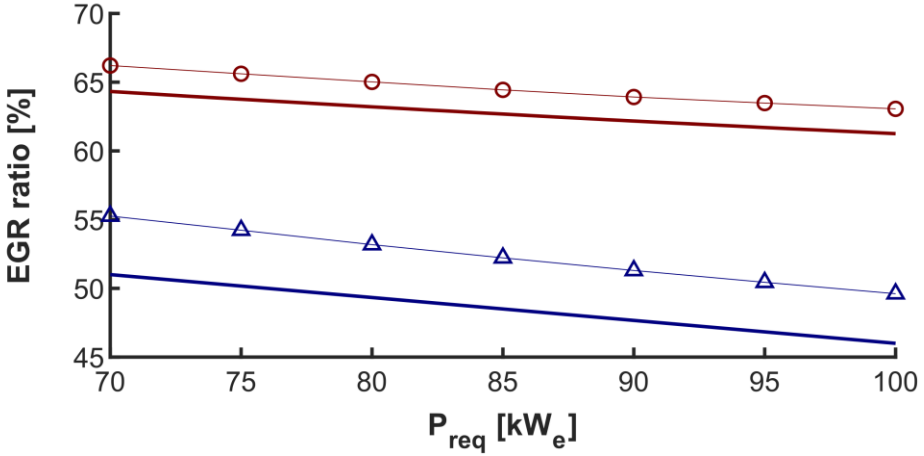


CO_2 concentration is lower for the humidified case.

The EGR ratio is lower in the humid case, due to presence of water.



Micro gas turbine cycle humidification with EGR for highly-flexible carbon-clean power production

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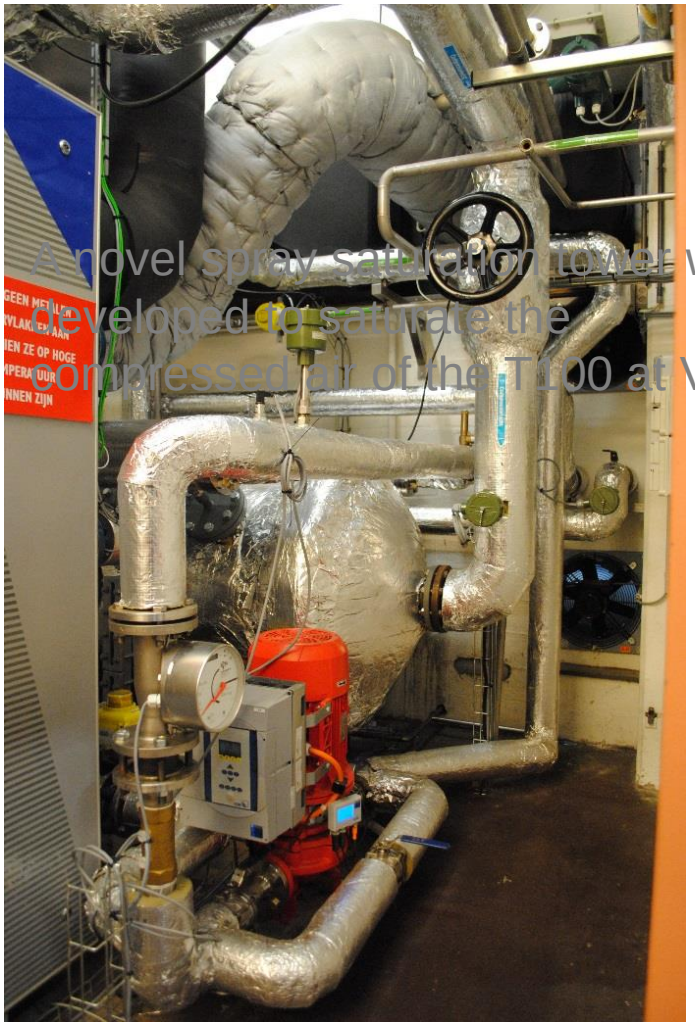
Experimental validation

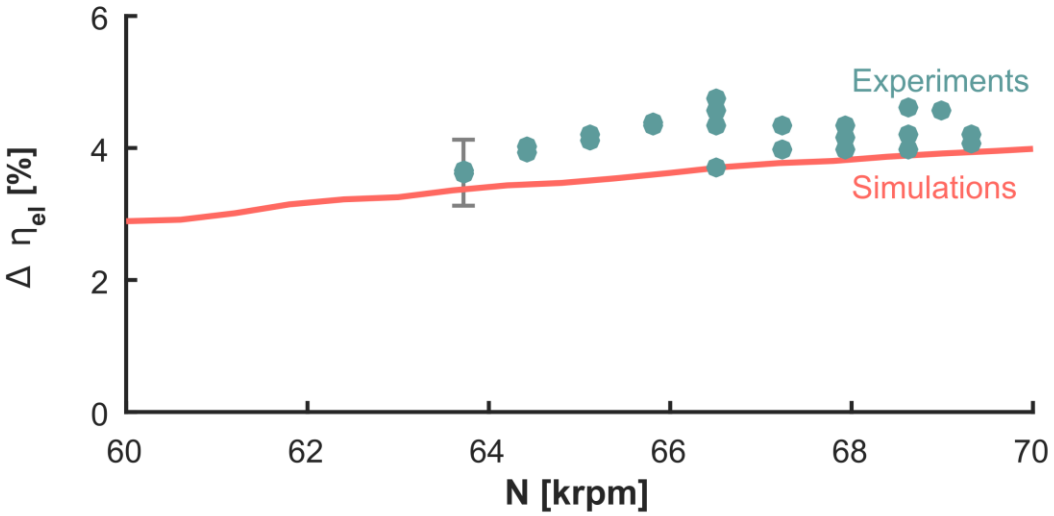
Experimental validation of the humidified operation was performed at the VUB T100 test rig.

The saturation tower was integrated in the mGT cycle.



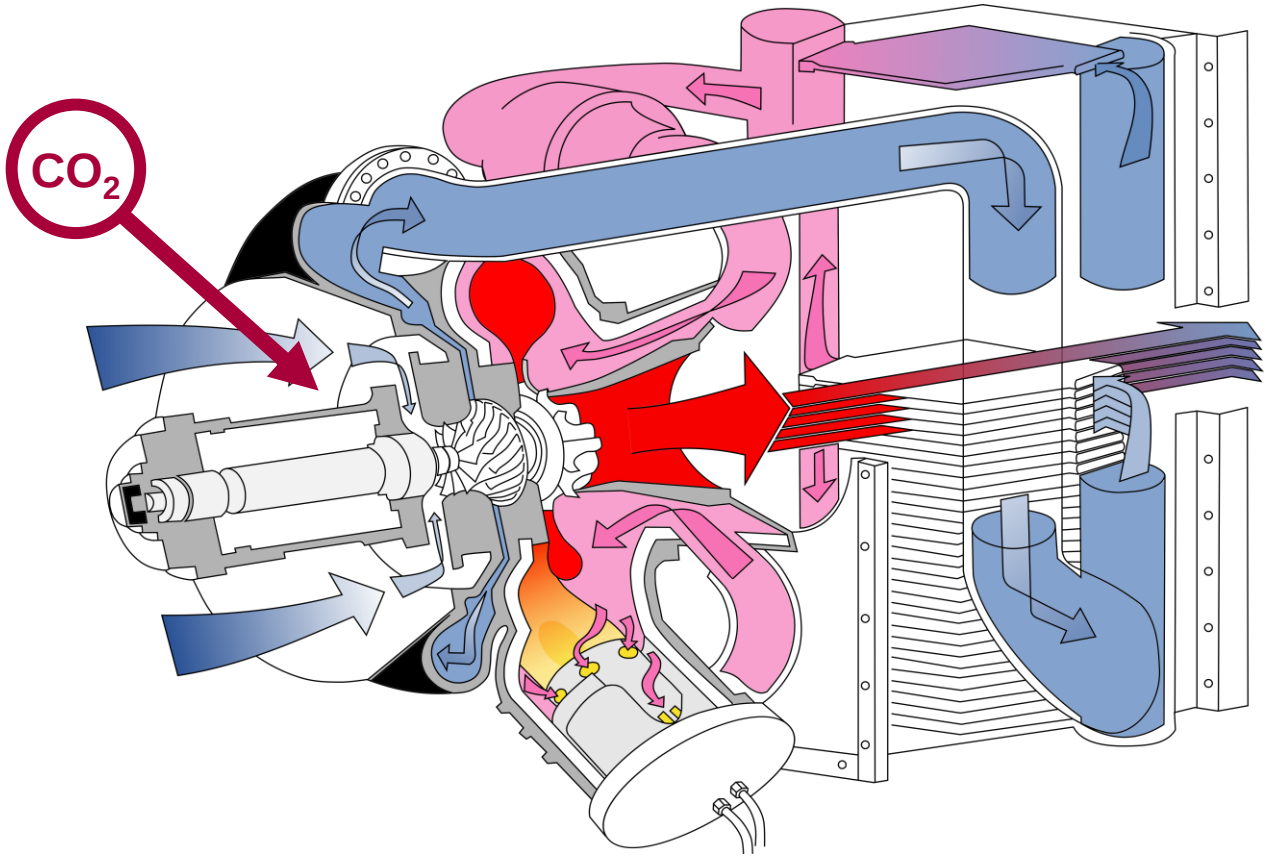
A novel spray saturation tower was developed to saturate the compressed air of the T100 at VUB

Experimental validation indicates the numerical models are capable of predicting the cycle performance



The measured increase in electrical efficiency at constant rotational speed is in agreement with the predicted efficiency increase.

The impact of EGR was emulated by injection CO_2 in the compressor inlet.



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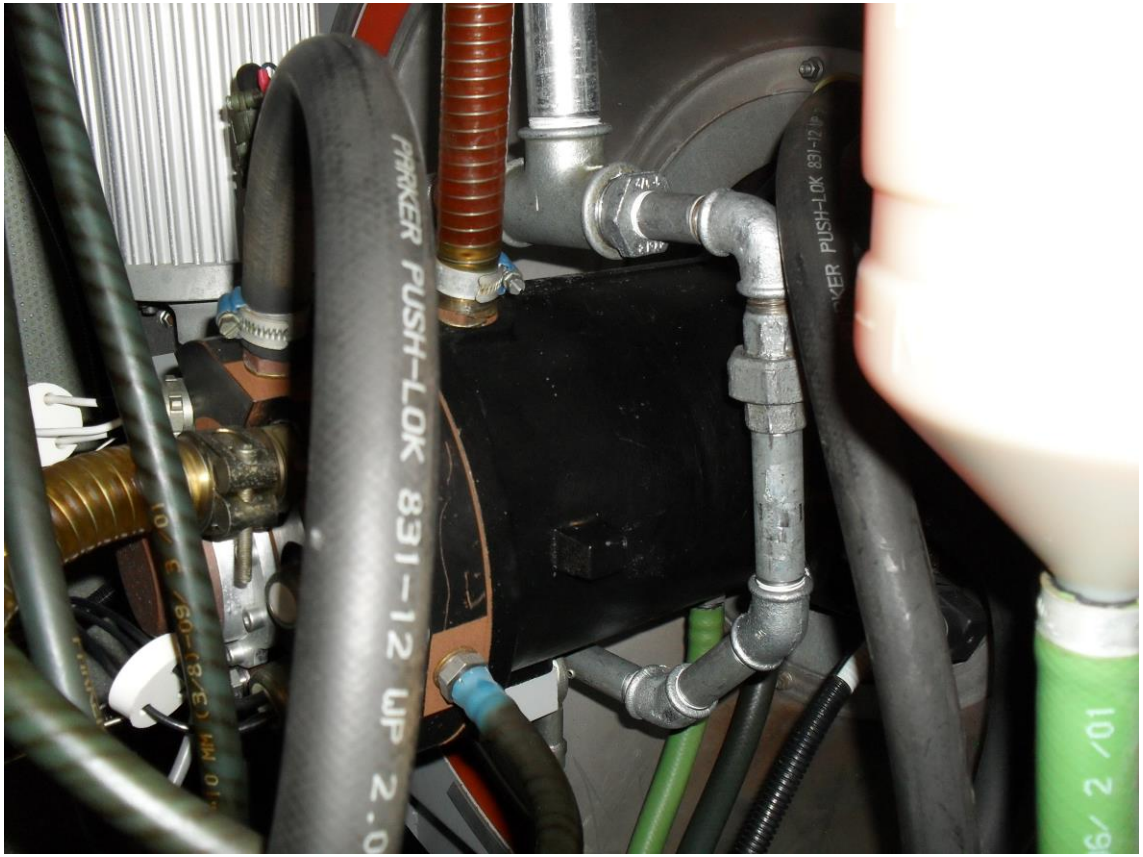

Only a limited amount of CO_2 could be injected showing no significant impact.

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Combining GT cycle humidification with EGR allows highly-flexible carbon-clean power production.

Impact of humidification and EGR on the mGT performance was modelled.

Both models predict similar behavior for humidification and EGR.

- humidification increases efficiency
- EGR increases CO_2 content

Both models have been (partially) validated experimentally.

Results show potential for application on small-scale.

Still potential to be unlocked.

Real value of the advanced model should be proven by scaling up to large plant models.

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