Supercritical CO_2 Power Cycles Symposium

Poster summary paper

Optimization of CO2 injection, used as a cooling agent, into a prototype high-pressure combustor for H2 oxy-combustion in sCO2

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The ongoing investigation is part of the project Horizon Europe HORIZON-CL5-2021-D3-03-02 - HERMES (**H**ighly **E**fficient super critical ze**R**o e**M**ission **E**nergy **S**ystem) where the main objective is to develop and validate a closed-loop renewable energy system based on semi-open directly fired supercritical gas turbine engine operating on renewable fuels (e.g. hydrogen or methanol, methane) with net-zero greenhouse gas emissions. The current phase of the project is focused on a numerical investigation of the effect of cooling supercritical CO2 on a mixing process with hydrogen and oxygen and supercritical CO2 and heat exchange in a combustion chamber during:

a) Cold flow
b) Hot flow
c) Oxy-combustion of hydrogen

The analysis of the cold flow was carried out in ANSYS Fluent 2023R2 software. A steady-state simulation was performed for the gas phase which was modeled by applying an Eulerian approach. The turbulence effect was simulated by the realizable k-ε approach. The SIMPLE algorithm was applied for pressure-velocity coupling. Second-order schemes were used for spatial discretization.

The flows of hydrogen, oxidant (O2 + CO2), and cooling CO2 were monitored inside a high-pressure combustor. The point was to determine optimal flow conditions and sufficient mixing resulting in a good environment for ignition. Fig. 1 illustrates the mesh that was generated for the fluid domain which consisted of 2.32 million cells with an average orthogonal quality of 0.77.

The flow conditions for the simulation were as follows:

H_2 mass flow rate: 0.02 kg/minute

Cooling CO_2 mass flow rate: 1.7 kg/minute

Oxidant (O_2 with CO_2) mass flow rate: 1 kg/minute where O_2 mole fraction equals 0.3.

The operating pressure equals 8 MPa and inlet temperatures of all gases equal 330K

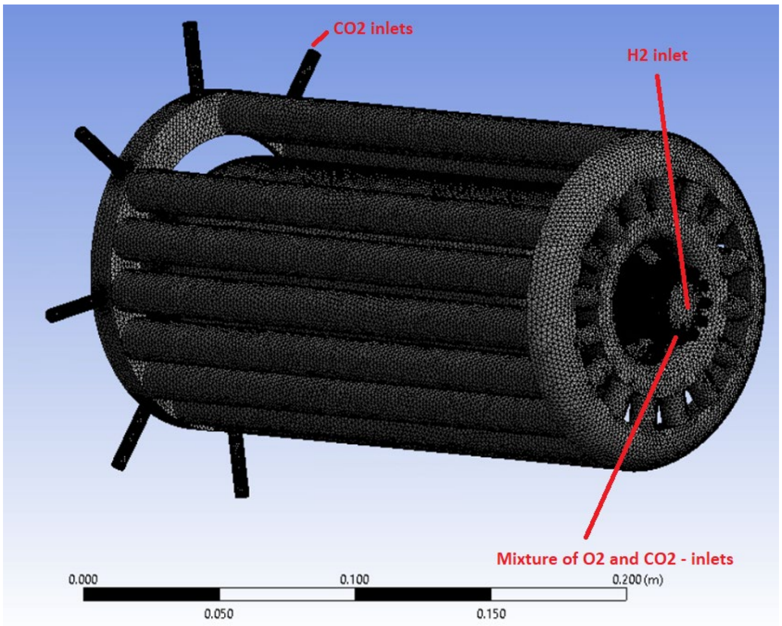
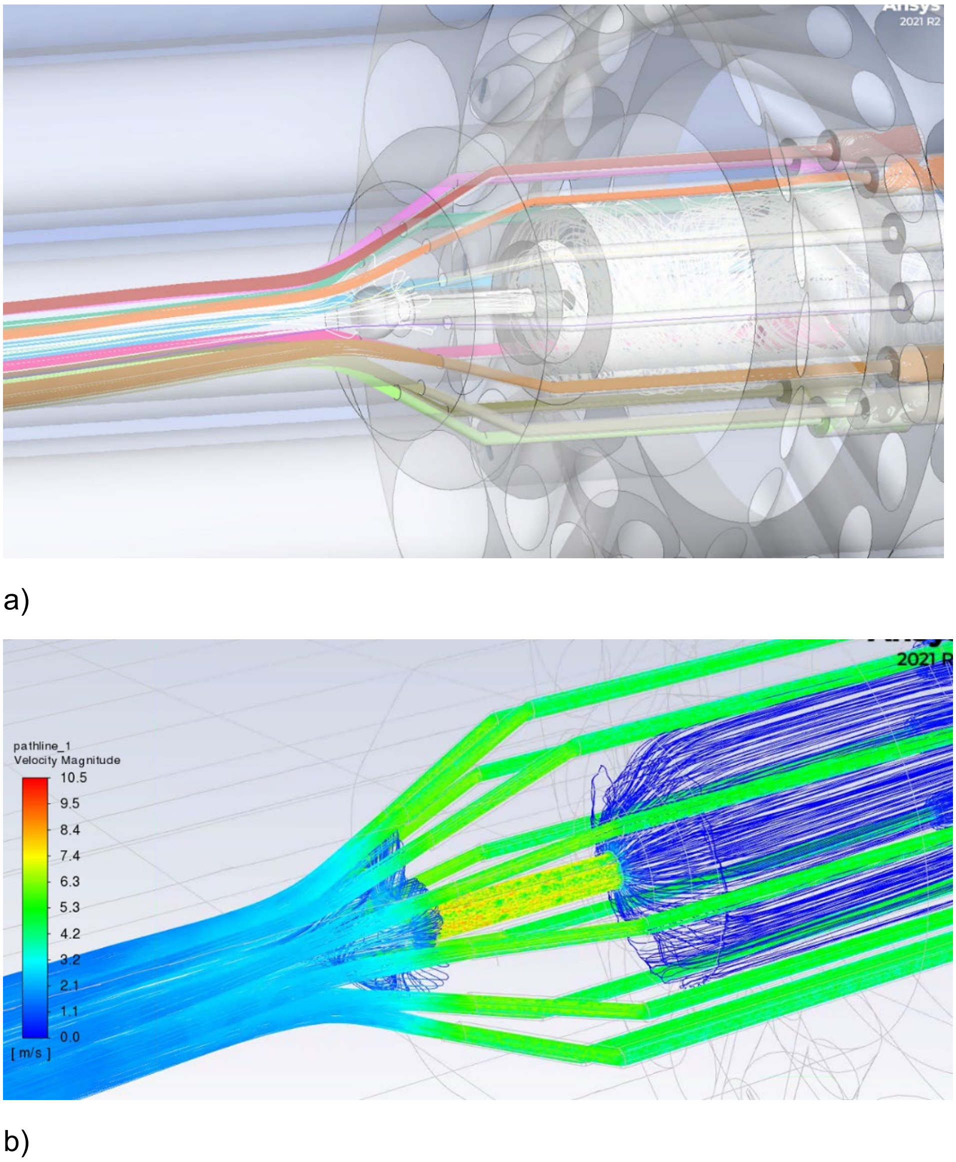


Fig. 1 Numerical mesh of the high-pressure reactor’s fluid domain.

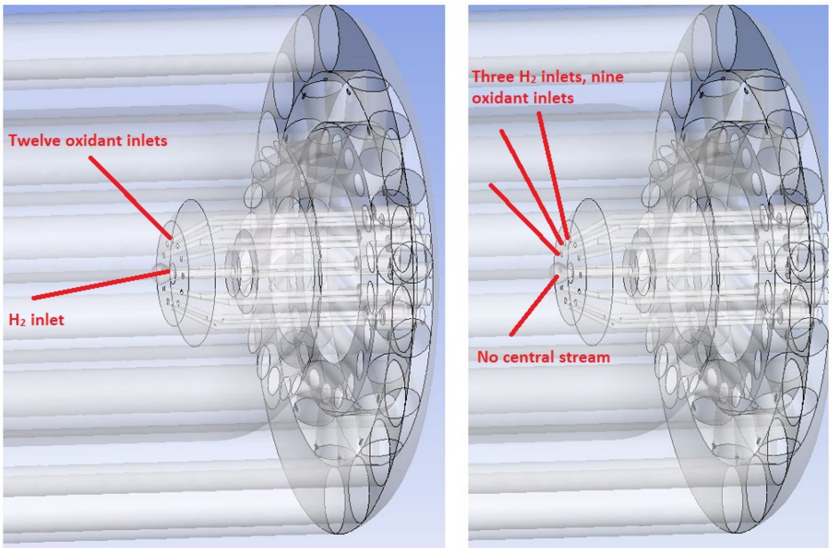
Fig. 2 from the numerical investigation indicates insufficient mixing of hydrogen with oxidant (CO2+O2), which would deteriorate the optimal conditions for the occurrence of ignition and effective combustion. Even though the bluff body was used to destabilize the hydrogen flow and ensure better mixing with the oxidant, eventually, the mixing was not sufficient and the current geometry had to be modified. Fig. 3 presents the general concept of that modification. The idea was to remove the central inlet of hydrogen and to apply it circumferentially along with the oxidant. Nine inlets would be used for oxidant, and three for hydrogen.



a)

b)

Fig. 2 Pathlines of H_2 and mixture of O_2 and CO_2. **a)** a given color corresponds to a specific stream. White color – H_2, rest of the colors – streams of the mixture of O_2 and CO_2, **b)** Velocities of the streams presented in **a)**



a)	b)

Fig. 3 Change of conception of H_2 and oxidant supply. a) H_2 supply before modification, b) H_2 supply after modification

Fig. 4 depicts identification pathlines for hydrogen and for the oxidant. With respect to the previous reactor configuration, the modified one ensures better mixing characteristics of the fuel with oxidant which would provide better ignition and combustion characteristics.

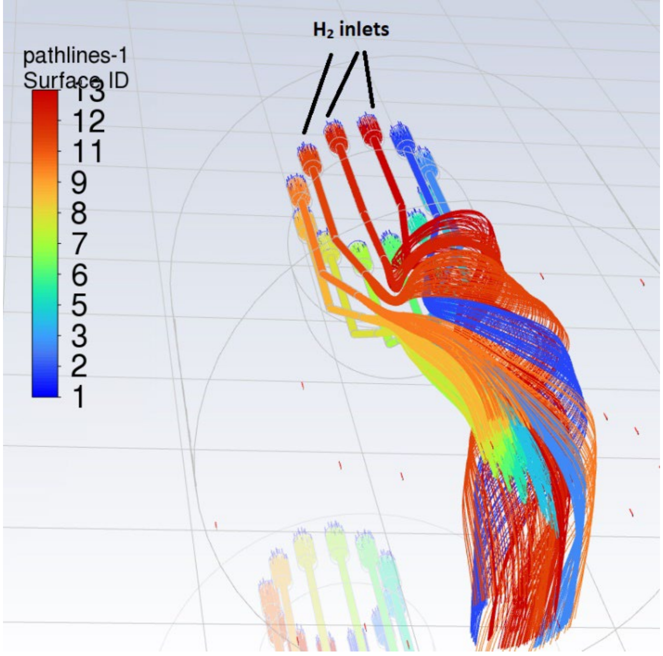
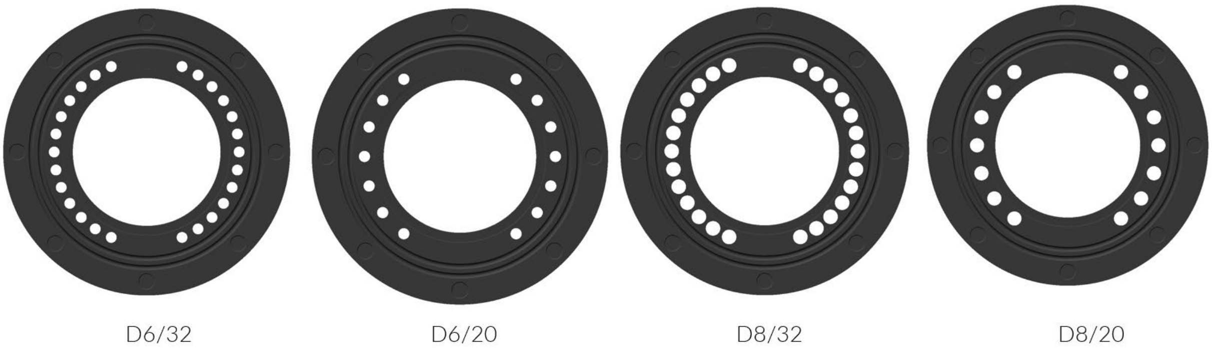


Fig. 4 Identification pathlines of H_2 and oxidant streams for 80 bars. Streams 11, 12, and 13 correspond to H_2. The rest of the streams correspond to oxidant.

Fig. 5 illustrates different combustor configurations with different number of pipes and pipe sizes of cooling sCO2. The goal was to choose the most optimum configuration as regards the heat transfer between the cooling sCO2 and the fluegas inside the combustion chamber. The analysis was carried out for hot flow conditions assuming a constant temperature of flue gas – 1300K.



D6/32 D6/20 D8/32 D8/20

Fig. 5 Different number of pipes and pipes size of cooling sCO2

Fig. 6 illustrates outer metal temperatures for different sCO2 system configurations. In order to have the lowest metal temperature, 32 pipes with 8mm in size were selected as the most optimum ones.

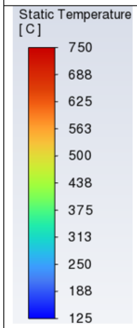
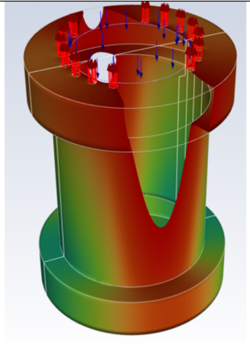
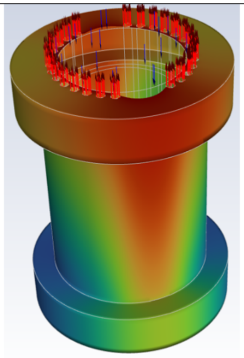
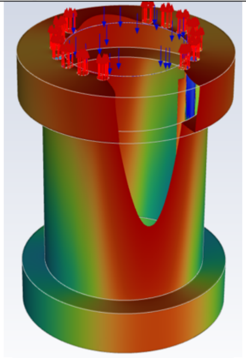
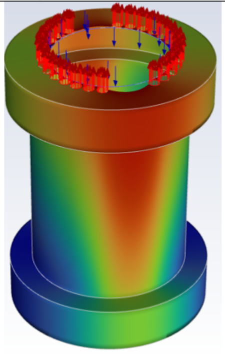
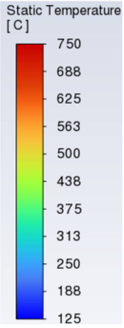
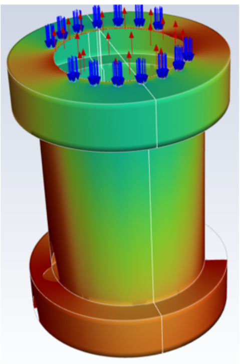
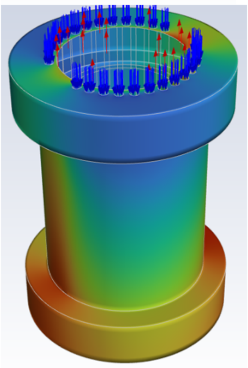
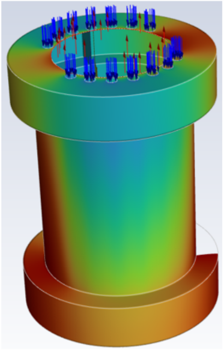
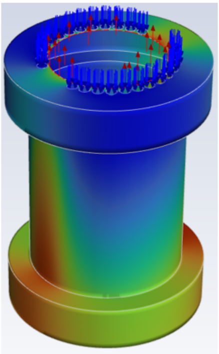
Temp [°C]	6x20 CO2 mass flow rate: 1.7 kg/min CO2 velocity (Fluent-result): 0.113 m/s Cooling CO2 at outlet: 537K	6x32 CO2 mass flow rate: 1.7 kg/min CO2 velocity (Fluent-result): 0.061 m/s Tout CO2 – 610K	8x20 CO2 mass flow rate: 1.7 kg/min CO2 velocity (Fluent-result): 0.064 m/s Cooling CO2 at outlet: 596K	8x32 CO2 mass flow rate: 1.7 kg/min CO2 velocity (Fluent-result): 0.0344 m/s Cooling CO2 at outlet: 646K
 Static Temperature [C] 750 688 625 563 500 438 375 313 250 188 125				
 Static Temperature [C] 750 688 625 563 500 438 375 313 250 188 125				

Fig. 6 Outer metal temperatures for different sCO2 system configurations.

Conclusion

The analysis of results of numerical modeling resulted in the development of the configuration and design of a high-pressure combustor for oxy-combustion of fuel in supercritical CO2 conditions integrated with a line of loading of fuels/oxidants at high pressure. Especially, the location of the system of injections to the combustor was determined. Also, the acquisition data system and concept of system steering of combustion are proposed..