Centrifugal Compressor and Expander for SOFC/IC System

ABSTRACT

In some fuel cell applications, pressurizing the fuel cell allows for higher power and lower temperatures within the fuel cell. This pressurization requires a compressor. The efficiency of the system depends on the efficiency of the compressor system. One such application of a pressurized fuel cell that has been under development is using a solid oxide fuel cell (SOFC) with an internal combustion (IC) engine as an electric generator. This project focused on developing a high efficiency centrifugal compressor and expander system that would meet the efficiency and pressure requirements for a SOFC/IC system. Various compressor and expander configurations were modeled, the most suitable configuration was selected, and a test bench was designed to study the performance of the selected configuration. The test bench was assembled, with testing currently underway.

SIGNIFICANCE

As compared to other power generating systems, fuel cells are much more efficient, with SOFC efficiencies >60%. In most fuel cell applications, fuel cells are operated at ambient pressure, or just above ambient pressure. However, in this application, pressurization allows for higher power and lower temperatures within the fuel cell. This pressurization requires a compressor. Because some of the energy produced by fuel cells is used to power other components in the system, the efficiency of the entire system depends on the efficiency of the compressor and expander system [1,2].

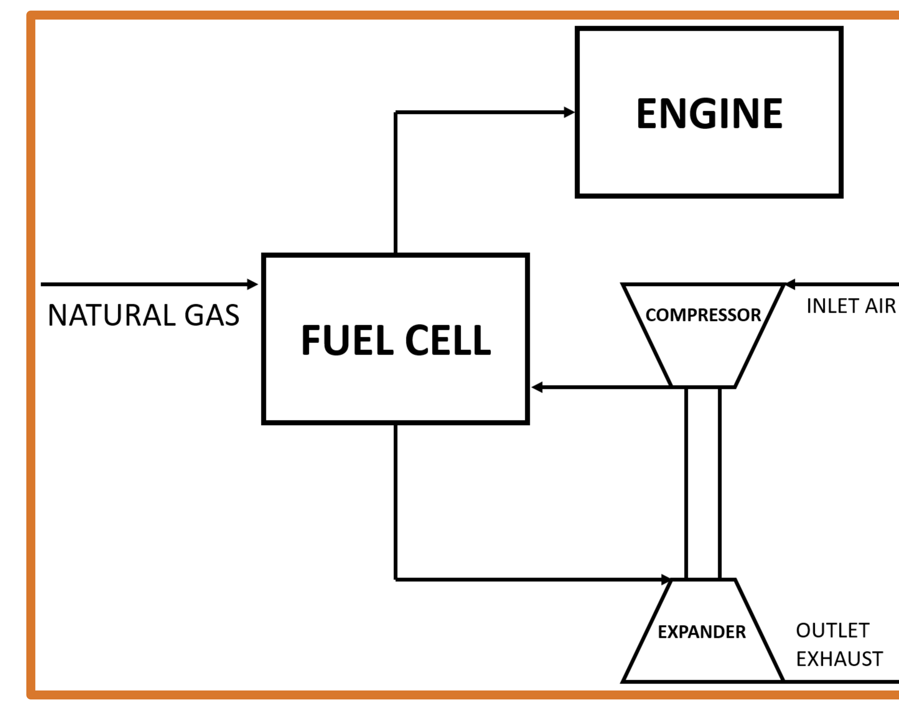

Figure 1: Simplified hybrid SOFC/IC schematic (adapted from [1]).

RESEARCH CHALLENGES

In Figure 3, it was evident that the SOFC/IC operating conditions were outside of positive displacement (PD) type devices. However, in Figure 4, the SOFC/IC operating conditions were well within the highest efficiency of a centrifugal device. Further testing was required to make conclusions about the validity of using centrifugal devices under SOFC/IC conditions.

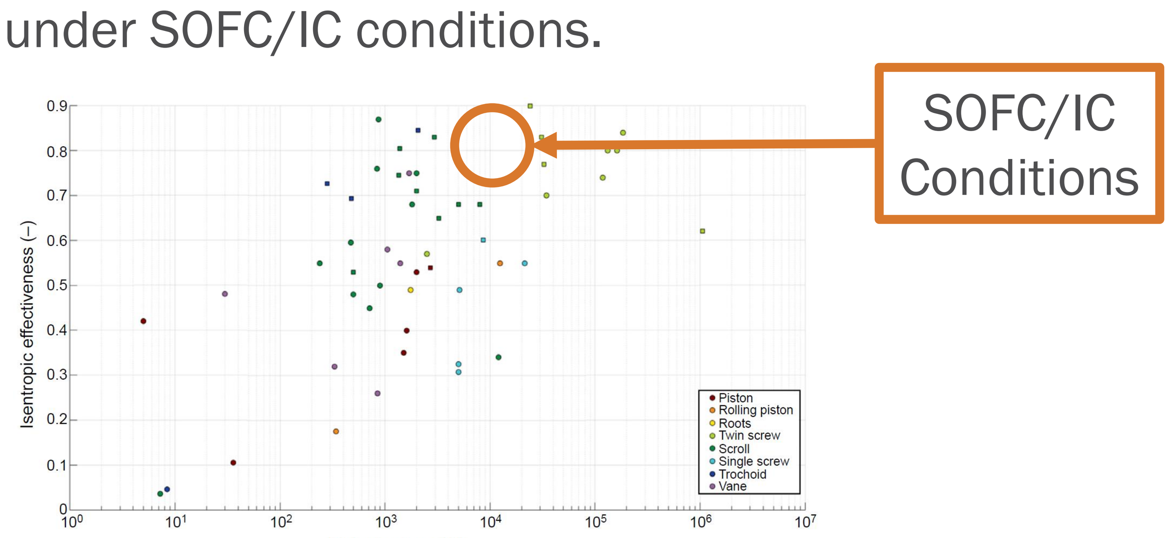

Figure 3: Efficiency vs. power for PD devices (adapted from [3]).

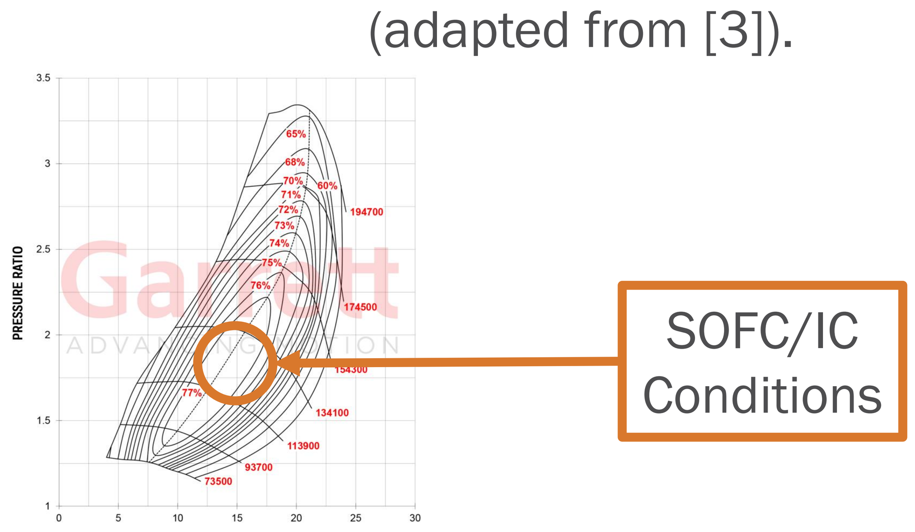

Figure 4: Pressure ratio vs. mass flow for a centrifugal device (adapted from [4]).

SYSTEM DESIGN

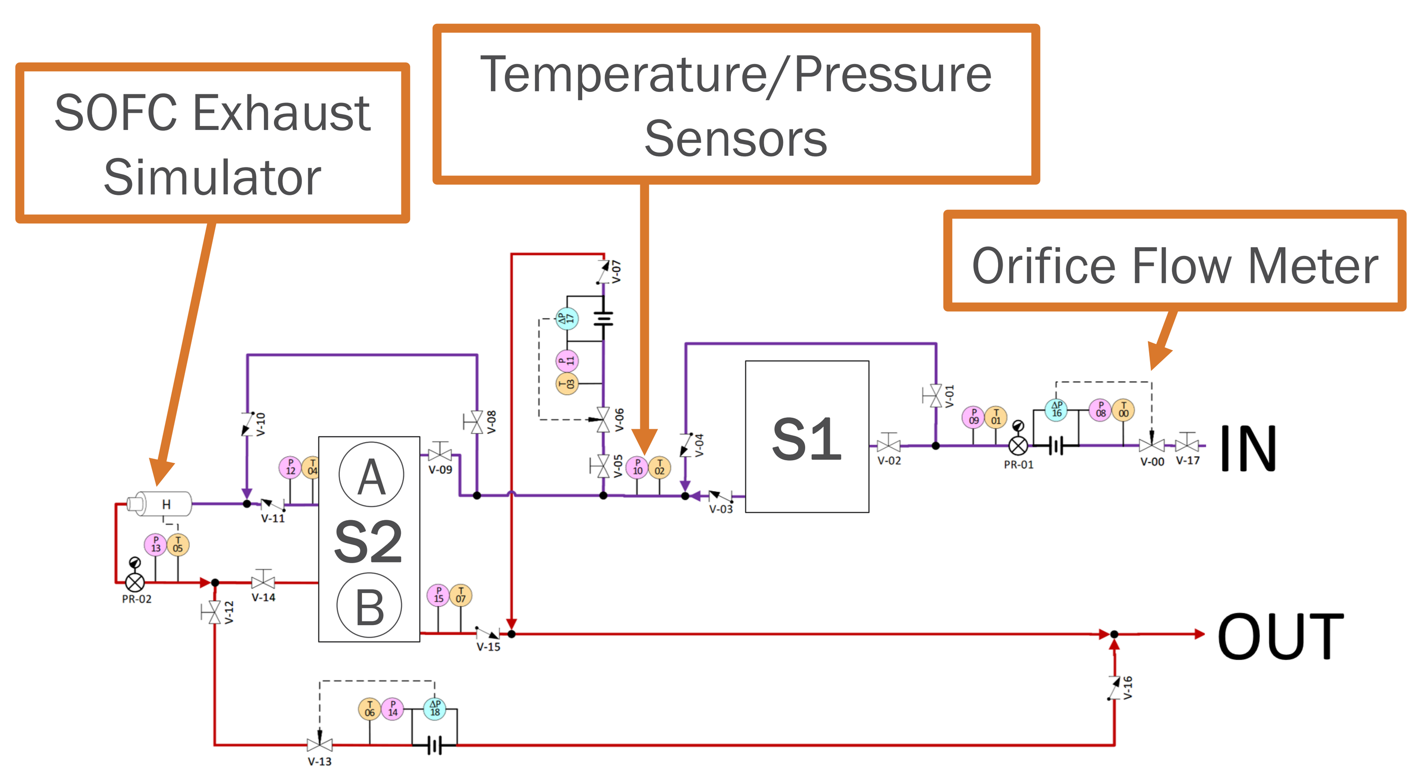

Figure 5: Test bench piping and instrumentation diagram.

A testing bench was created to test the performance of the compressor and expander design. Mass flow rates were measured using orifice flow meters. Check and ball valves were placed to manage the flow of air through the system. For testing purposes, the air that would be redirected to the engine is now being exhausted. An electric air heater with a split in flow is used to simulate the fuel cell exhaust. The final test bench design can be seen in Figure 5.

SYSTEM ASSEMBLY

To assist in assembly, a 3D model of the test bench was generated starting with the support stand. Unistrut was used to allow for design flexibility. Components were placed onto the support stand, and the pipe lengths were determined. The 3D model generated can be seen in Figure 6. The system was assembled using the 3D model as a guide. Some minor changes were made to accommodate issues with assembly. The completed assembly can be seen in Figure 7.

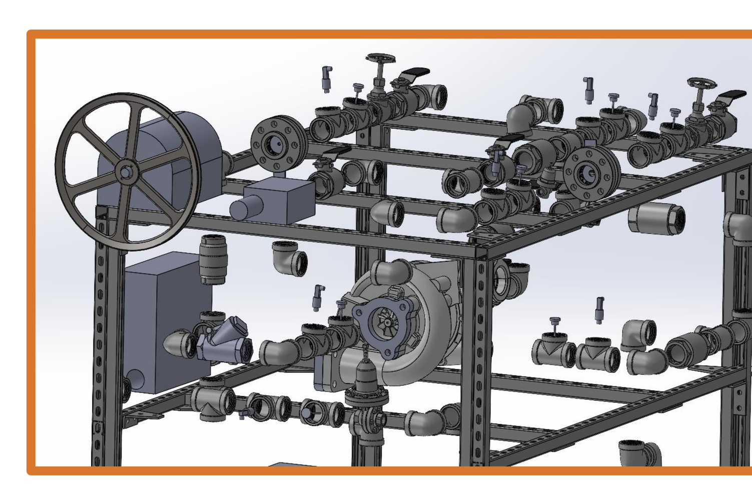

Figure 6: 3D model of test bench.

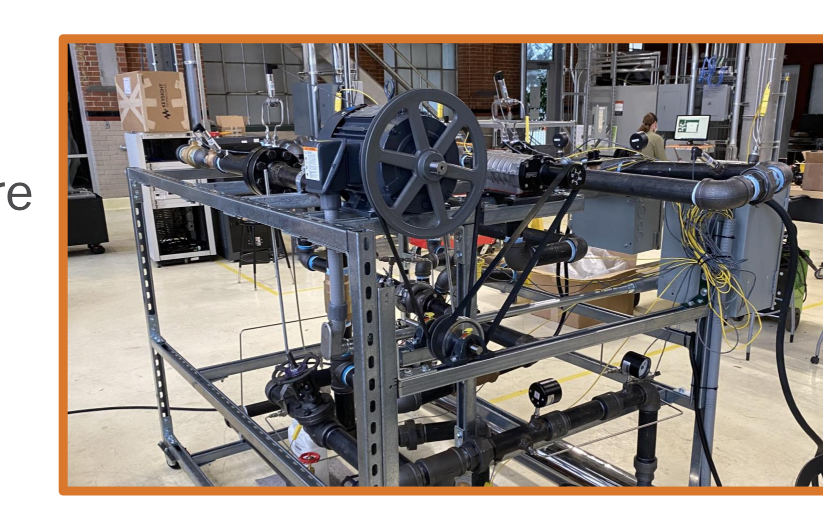

Figure 7: Picture of completed assembly.

SYSTEM TESTING

Testing of the system occurred after the assembly was completed. All components were tested individually before testing the system as a whole. Changes were made as needed, and initial results can be seen in Table 1. Testing will continue into my graduate studies here at Colorado State University beginning this summer.

Table 1: Testing results at air heater temperature of 155 ^{o}C.

Component	Temperature (^{o}C)	Pressure (kPa)	Mass Flow (g/s)
Before S2A	33	109.9	29
After S2A	14	110.9	29
Before S2B	155	103.3	29
After S2B	82	101.7	29

CONCLUSIONS

The initial results collected indicate that the test bench designed will be able to measure the performance of the compressor and expander configuration selected. However, futher testing is needed to make conclusions on how the selected compressor and expander configuration will perform under SOFC/IC operating conditions.

REFERENCES

[1] Braun, Robert J., et al. “Development of a Novel High Efficiency, Low Cost Hybrid SOFC/Internal Combustion Engine Power Generator.” ECS Transactions, vol. 91, no. 1, 2019, pp. 355–360., doi:10.1149/09101.0355ecst

[2] Zhang, Yuemeng, et al. “Performance Improvement of Fuel Cell Systems Based on Turbine Design and Supercharging System Matching.” Applied Thermal Engineering, vol. 180, 29 July 2020.

[3] “Positive Displacement Expanders for Organic Rankine Cycle Systems.” Organic Rankine Cycle (ORC) Power Systems: Technologies and Applications, by Ennio Macchi and Marco Astolfi, Woodhead Publishing, 2017, pp. 361–396.

[4] GT2052 Small Frame Turbocharger - GT Series. 27 Jan. 2020, www.garrettmotion.com/racing-and-performance/performance-catalog/turbo/gt2052/.

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