DYNAMIC FLOW OF MICRO-CHANNELS IN A CERAMIC HEAT EXCHANGER

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Abstract

This paper presents a comparison of flow between four possible designs for a ceramic, high temperature, heat exchanger that is used as a sulfuric acid decomposer, which may be used for hydrogen production within the sulfur iodine thermo-chemical cycle. The decomposer is manufactured using fused ceramic layers that allow creation of tailored micro-channels with dimensions below one millimeter. The baseline design uses parallel straight channels with rectangular cross sections. This design will be compared with other proposed designs where varying cross sections and serpentine flow paths can improve the heat transfer with minimal effects on the pressure drop. Measurements have been taken using a dynamic pressure mat that has been calibrated to allow for precise measurements of the flow data. Results of this research are used as a basis for investigation of the optimal design of the decomposer that can provide maximum thermal performance while maintaining low pressure drops and thermo-mechanical stresses within system.

Introduction

Metallic heat exchangers have been used for decades and are the ideal option for lower temperature ranges, generally below 350°C, because of their low material cost and ease of manufacture. However, the lifetime of metal heat exchangers is generally limited by low operating temperatures or corrosive environments. While some super alloys can be used in these environments, ceramics have become the necessary choice. Ceramics are capable of enduring such environments and have been chosen because of this ability.

In determining the ceramic to be used in the proposed sulfuric acid decompose heat exchanger, several material and mechanical properties are required. Values of these properties, for some candidate ceramic materials, are shown in Table 1. The values of the required properties and consideration of manufacturing cost lead to SiC being chosen.

Table 1. Material properties of different ceramics.

Material	Thermal Conductivity (W/(m*K))	Strength (MPa)	Fracture Toughness (Mpa*m$^{1/2}$)	Normalized Thermal Shock Parameter	Creep Resistance
SiC	125	360	5	1	Excellent
$MoSi_2$	66	350	4	0.49	Good
Ti_3SiC_2	25	580	6	0.4	Good
Si_3N_4	15	500	5	0.42	Excellent

Al_2O_3	27	250	3	0.02	Good

Experimental

Comparisons of flow between four possible designs for ceramic high temperature heat exchanger were made. The designs used parallel, straight channels with rectangular cross sections. Differences were manufactured into the height of the channels and the manifold thickness which led to and from the channels. Testing was done with acrylic parts at varying flow rates and consisted of three different test systems; a single pressure transducer, an array of pressure transducers, and a pressure sensitive mat. Channel and manifold thickness for the acrylic was divided into two categories; thick (3mm) and thin (1.5mm).

While pressure transducers are a standard method for acquiring pressures they are accompanied with several limitations. The significant limitation is the uncertainty between transducers calibrated to the same specifications. Effort was made to eliminate this by using a single transducer connected to a manifold of tubing to measure the pressure at the locations of interest, Figure 1. This method leads to the required assumption that the pressure remains constant as the measurement is taken. To avoid the above mentioned limitations, measurements were also taken using a dynamic pressure mat that was calibrated to the expected pressure.

Figure 1. Array of tubes used to determine pressure drop across heat exchanger.

In addition to the experimental tests, a model was designed and data acquired using a CFD program, Figure 2. This model was used first, to ensure that the pressure outlets could accurately measure the pressure in the channels and had no adverse affect on the flow, Figure 3, and second, as a numerical method with which the experimental data could be compared.

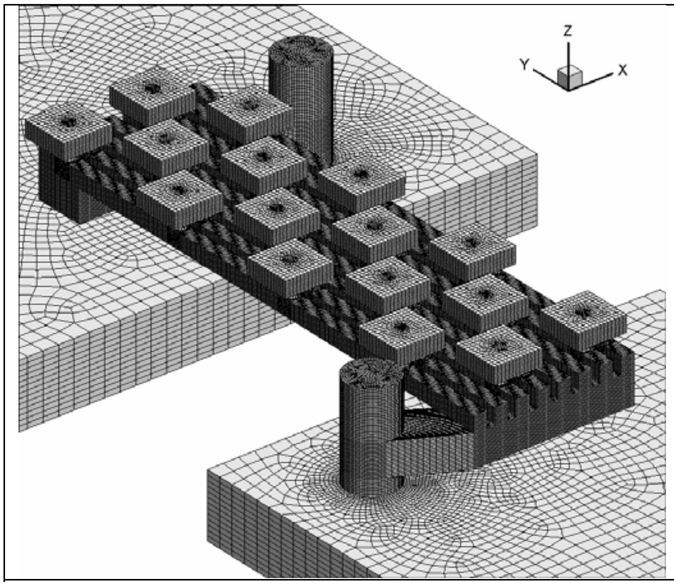

Figure 2. Heat exchanger mesh.

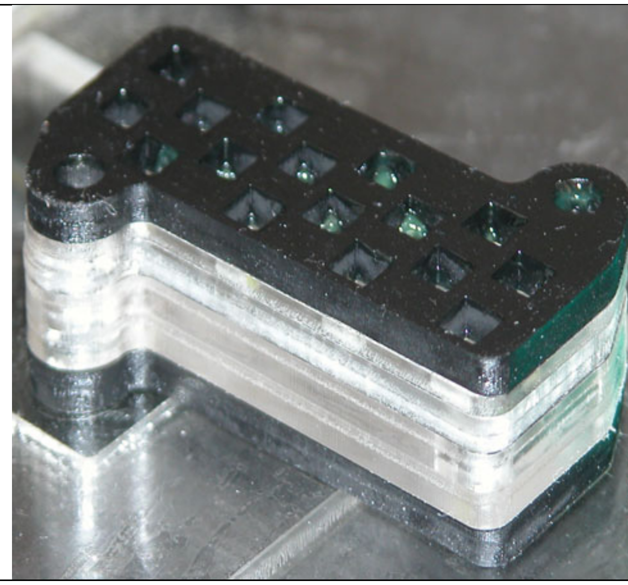

Figure 3. Plexiglas part with conformal top and bottom layers.

Results and Discussion

Results from comparisons of the experimental methods with the numerical data, as well as with each other were promising. The following data is for a manifold and channel thicknesses of 1.5 and 3mm respectively (alternate designs had similar results). Experimental flow tests (single pressure transducer and pressure transducer array, Figure 4) and numerical flow models show an average variation of 5% in both static and dynamic (transducer array) configurations.

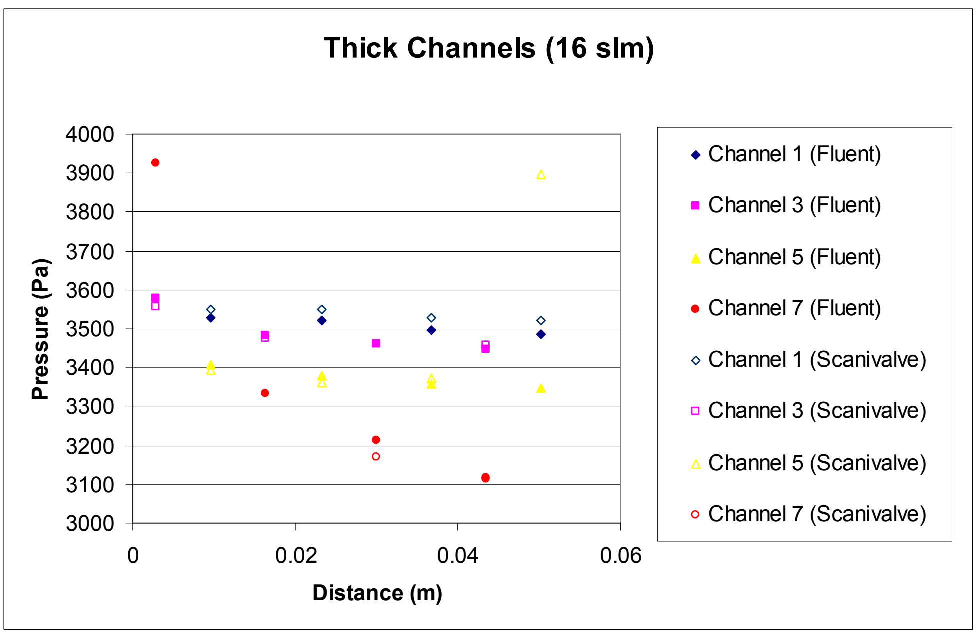

Figure 4. Comparison between pressure transducer array and CFD results.

Results for the pressure mat (which is always dynamic) vs. the numerical flow models had a variation closer to 10%, Figures 5, 6, and 7.

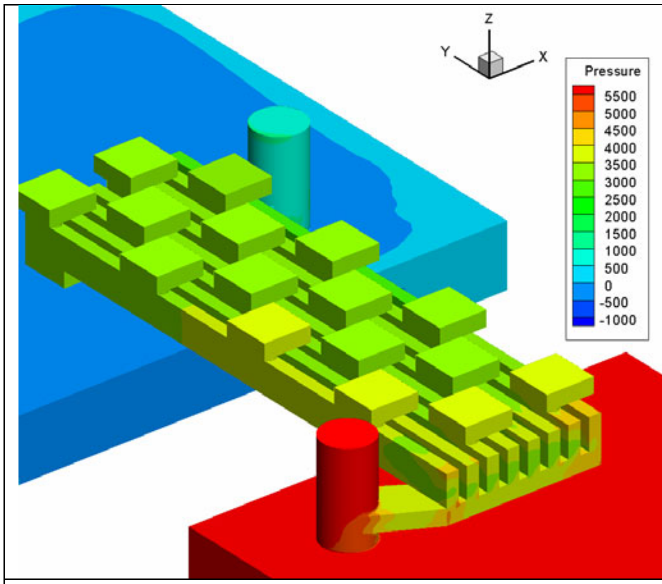

Figure 5. CFD results (pressure in Pa).

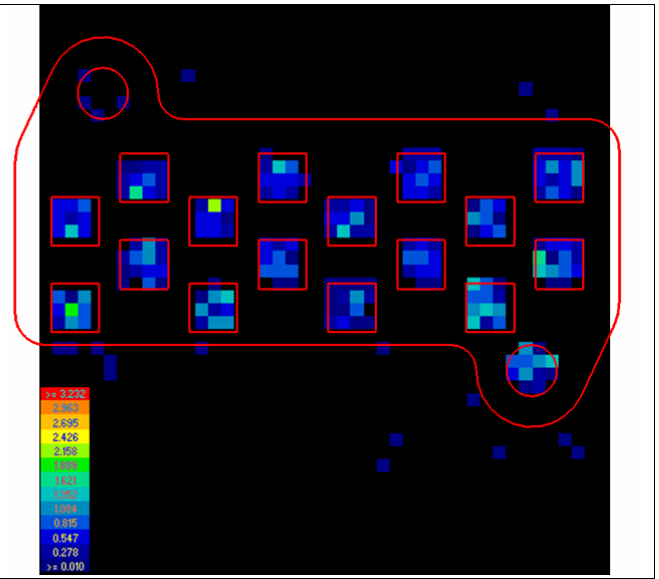

Figure 6. Pressure mat results (pressure in psi). Red outline corresponds with conformal layer.

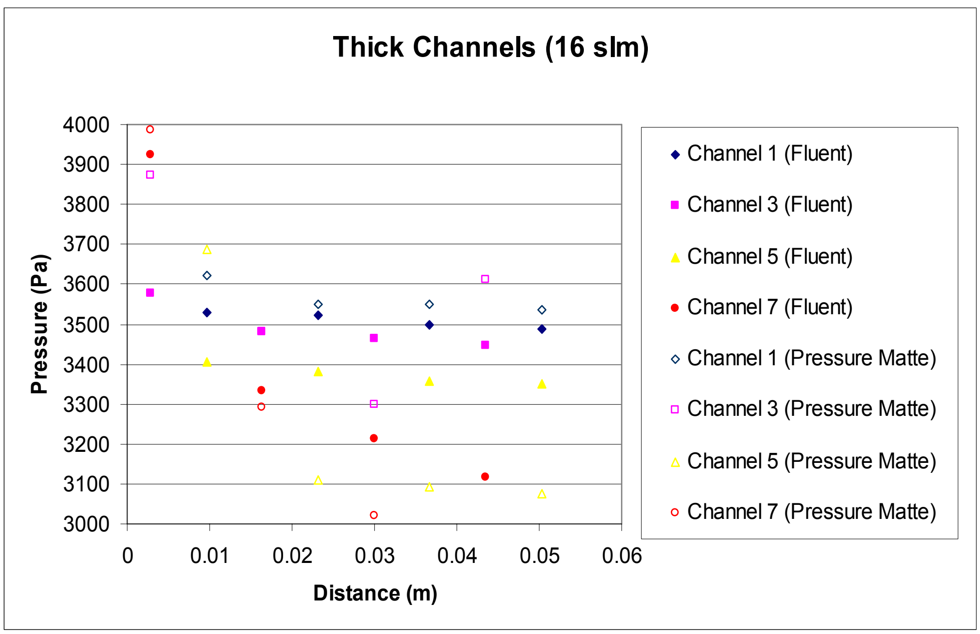

Figure 7. Comparison between pressure mat and CFD results.

The results acquired have filled two necessary requirements; 1) it has confirmed the ability for a resistive-based technology to acquire reasonable dynamic pressure data, and 2) it has validated the numerical results against experimental data. In addition to dynamic capabilities of the pressure mat, it also has user controlled sensitivity, and can be rapidly mounted to test fixtures. These abilities, along with verification of the numerical method, will be necessary as the channels and pressures are scaled to operating conditions.

Conclusion

Current results give confidence in the possible accuracy of using a resistance based pressure mat to obtain pressure/flow measurements. Results have validated the numerical method and will be used to optimize the heat exchanger design. Future work will lead to a more through understanding of dynamic pressures in straight channels and eventually various channel types.

Acknowledgement

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