Chauncey,

From

My Stochastic Physical Model (SPM) showed quite some time ago that thermodynamic effects had everything to do with the intensity and sustainability of exothermic reaction fronts in scrubber canisters. In cold water, a large delta T between gas in the scrubber and the outside water temp can rob heat from the canister and kill the reaction.

In the attached MathCad document, you'll see that assuming gas entering the canister is at water temp, 4°C, and that the heat from exothermic reactions is 1000 joules, that at your test conditions, and knowing the gas density at depth for each gas, the calculated gas temperature in air is much higher than in helium (64°C versus 32°C in heliox.)

Fourier's Law of Conduction says that the higher the differential between in-canister gas temperature and water temperature, the greater the conduction of heat to the water.

Without measuring the actual canister temperature, we can't know exactly what is happening. However, there are two possibilities to explain both what you report and what we saw in our own testing (which agrees with yours.)

With air, either 1) the higher gas temperature dries some of the absorbent granules, cutting down on reaction efficiency, or 2) the higher temperature gradient robs the absorbent bed of heat, again reducing absorbent efficiency.

Which pathway is favored depends on the level of insulation between the canister walls and the cold water. The greater the insulation, the more likely is mechanism 1. The poorer the insulation, the more likely is mechanism 2.
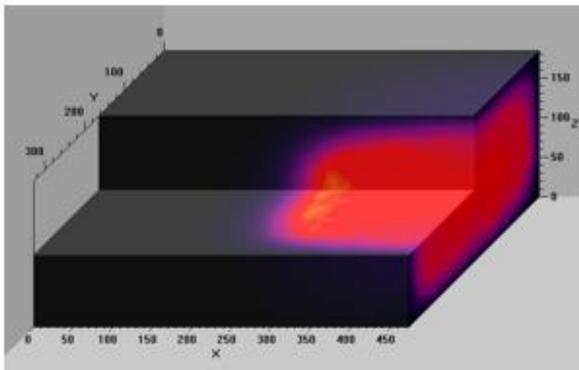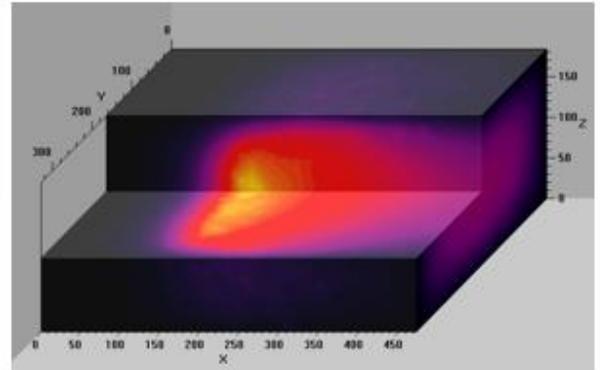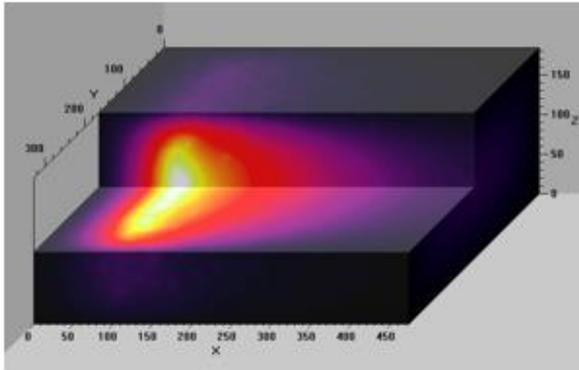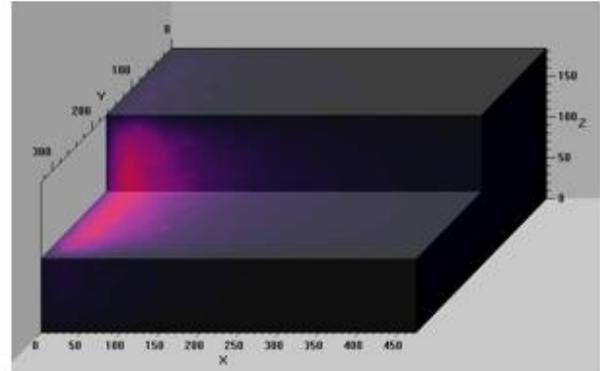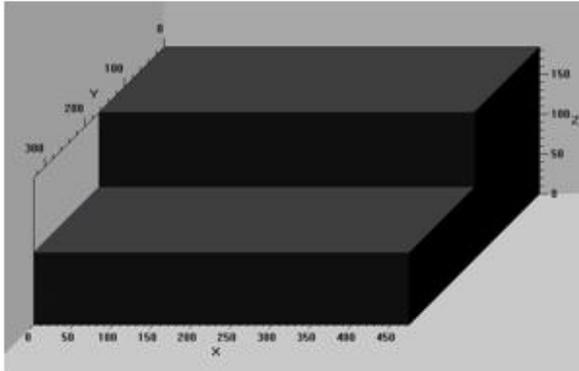
A cold-soaked 1° C canister in 1° C water briefly yields a localized absorption reaction flare, but then quickly cools.

Thermal Conductivity

Unlike the result of the above simulation, when thermal conductivity and the heat transfer coefficient were reduced to 10% of their previous value, the reaction front, once initiated, was sustained. The heat of reaction remained close to the reaction front rather than being conducted away.
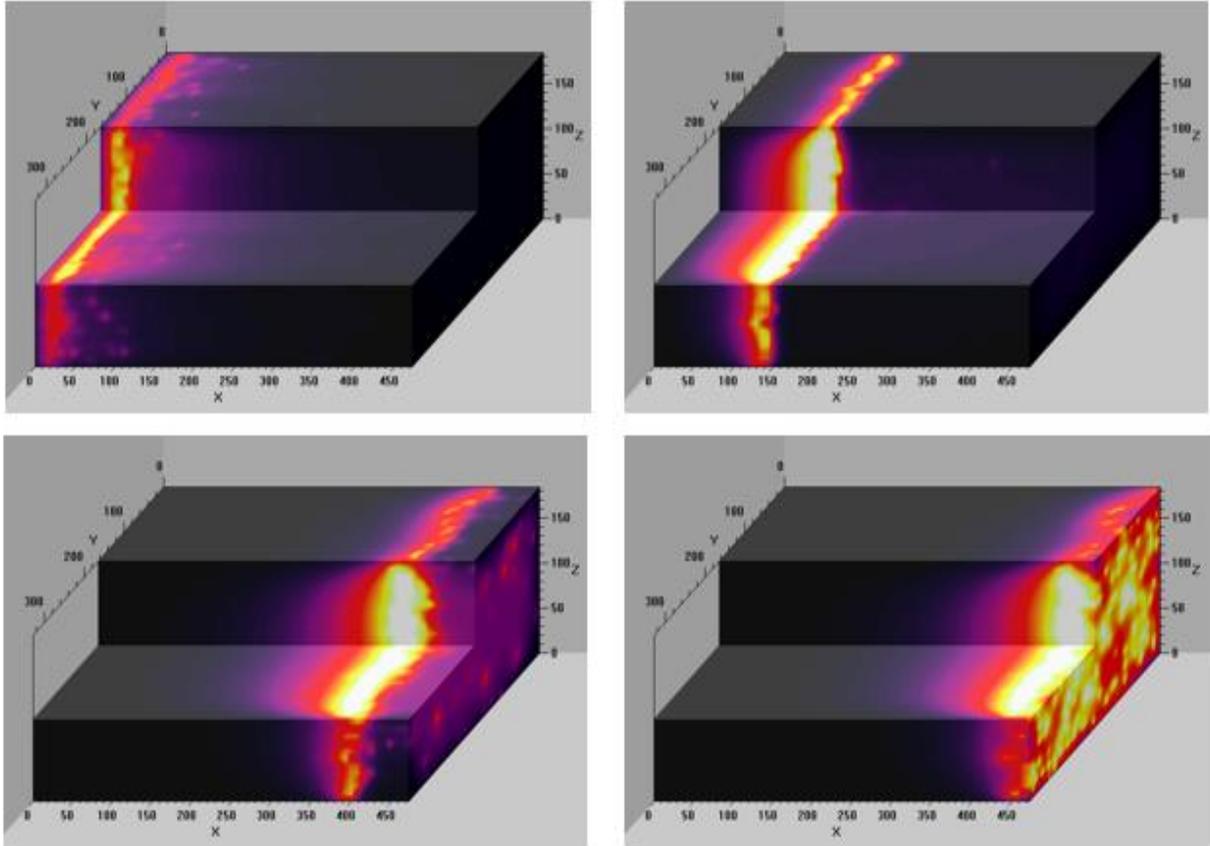
This result shows that in the previous instance with a pre-chilled canister, in qualitative accordance with Fourier's law of conduction,

$$\dot{Q} = -k \cdot A \cdot \frac{dT}{dx} \tag{18}$$

the combination of large thermal gradients $(\frac{dT}{dx})$ and high thermal conductivity (k) causes the rate of heat transfer $(\dot{Q})$ to rise enough to remove heat from the reaction front faster than it can be generated by exothermic reactions. The net result is reaction front cooling and diminished reactivity.

As always, convective heat loss also contributes to cooling and diminished reactivity.

Rebreather Test Data
Canister Duration in minutes

231	190
215	205
219	197

Canister Duration Means & SD
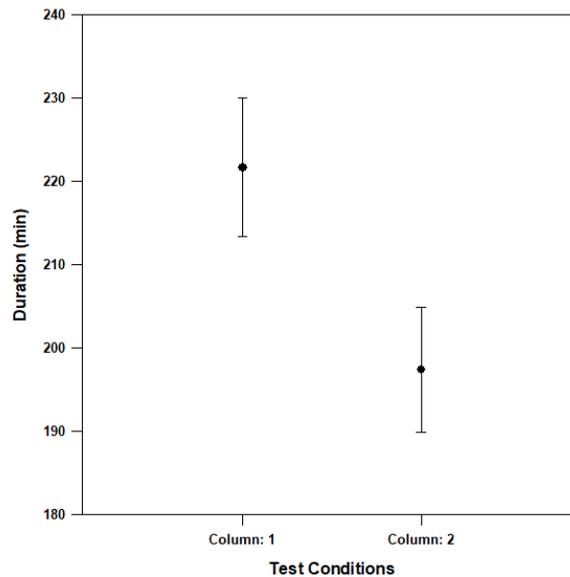
t-test   Thursday, March 10, 2022, 12:56:01 PM

Data source: Data 1 in Notebook1

Normality Test: Passed (P = 0.312)

Equal Variance Test: Passed (P = 0.913)

Group Name	N	Missing	Mean	Std Dev	SEM
Col 1	3	0	221.667	8.327	4.807
Col 2	3	0	197.333	7.506	4.333

Difference   24.333

t = 3.760 with 4 degrees of freedom. (P = 0.020)

95 percent confidence interval for difference of means: 6.364 to 42.303

The difference in the mean values of the two groups is greater than would be expected by chance; there is a statistically significant difference between the input groups (P = 0.020).

Power of performed test with alpha = 0.050: 0.777

Scrubber Canister Thermal Effects

air at 39.8 msw (130 fsw)

$Tin := 4 \ °C$

$q := 1000 \cdot J$

$\rho := 5.6 \cdot \dfrac{gm}{L}$

$vol := 3 \cdot L$

$m := \rho \cdot vol \qquad m = 16.8 \ gm$

$Cpm := 1 \cdot \dfrac{J}{K \cdot gm}$

$\Delta T := \dfrac{q}{m \cdot Cpm} \qquad \Delta T = 59.524 \ K$

$Tout := Tin + \Delta T \qquad Tout = 63.524 \ °C$

+

heliox at 100 msw (326 fsw)

$q := 1000 \cdot J$

$\rho := 2.5 \cdot \dfrac{gm}{L}$

$vol := 3 \cdot L$

$m := \rho \cdot vol \qquad m = 7.5 \ gm$

$Cpm := 4.81 \cdot \dfrac{J}{K \cdot gm} \qquad$ Cp for 9% oxygen and 91% He

$\Delta T := \dfrac{q}{m \cdot Cpm} \qquad \Delta T = 27.72 \ K$

$Tout := Tin + \Delta T \qquad Tout = 31.72 \ °C$

After 450 computational cycles, an initially 80°F canister in 34°F water. Gas is <u>air</u>. Heat capacity constant pressure ~ 1.0 J/(gm· K). As usual, the effect of pressure on Cp is considered nil.
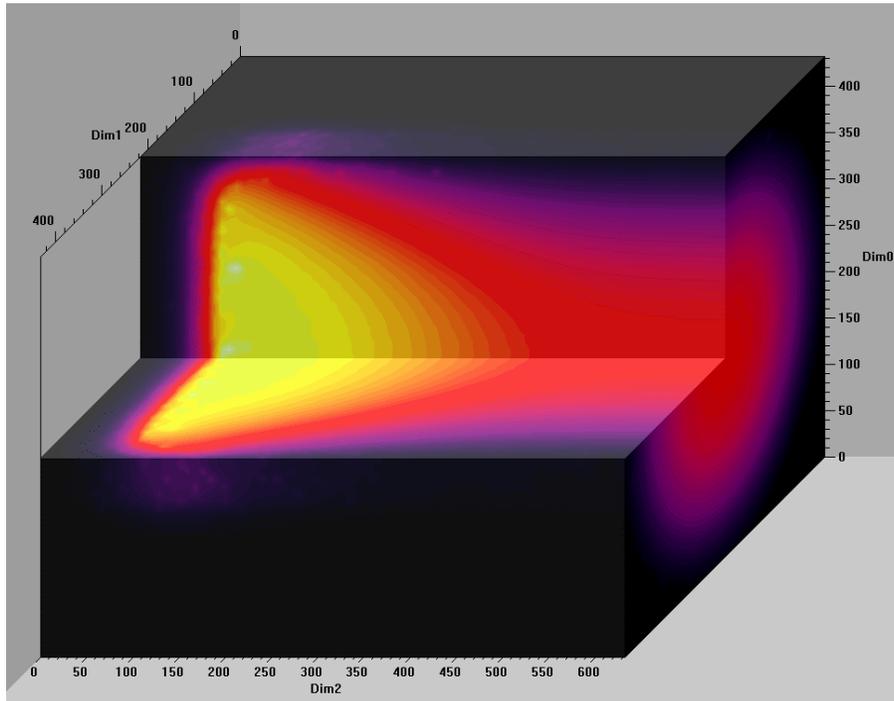
After 450 computational cycles, an initially 80°F canister in 34°F water. Gas is <u>heliox</u>. Heat capacity constant pressure ~ 5.0 J/(gm· K)