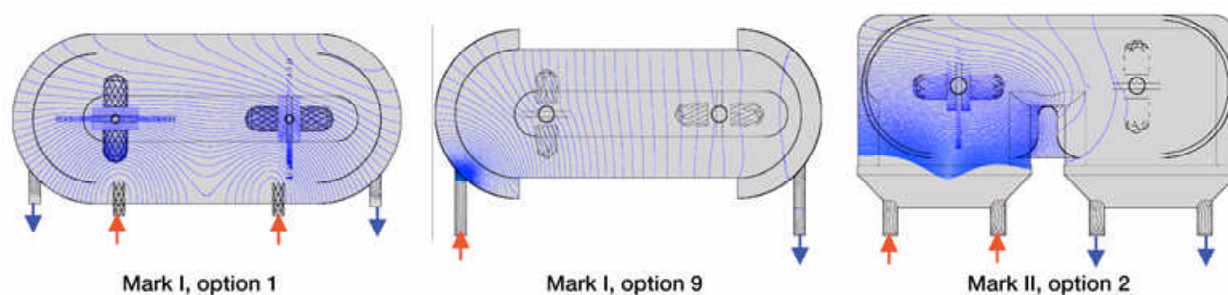


Design Study Conducted of a Stirred and Perfused Specimen Chamber for Culturing Suspended Cells on the International Space Station

A tightly knit numerical/experimental collaboration among the NASA Ames Research Center, NASA Glenn Research Center, and Payload Systems, Inc., was formed to analyze cell culturing systems for the International Space Station. The Cell Culture Unit is a facility scheduled for deployment on the space station by the Cell Culture Unit team at Ames. The facility houses multiple cell specimen chambers (CSCs), all of which have inlets and outlets to allow for replenishment of nutrients and for waste removal. For improved uniformity of nutrient and waste concentrations, each chamber has a pair of counterrotating stir bars as well. Although the CSC can be used to grow a wide variety of organic cells, the current study uses yeast as a model cell. Previous work identified ground-based protocols for perfusion and stirring to achieve yeast growth within the CSC that is comparable to that for yeast cultures grown in a shaken Ehrlenmeyer flask.



Isoconcentration contours generated by perfusion at 0.9 ml/min and no stirring.

Long description of figure The following images show the concentration field in all three chambers with perfusion but no stirring. The isoconcentration contours developed at the midheight plane vary significantly among the different chambers. Left: Mark I, option 1-- There are two small inlets at the bottom center of the figure with hemispherical contours emanating from them. There are two small outlets at the left and right side of the chamber. The isoconcentration contours are roughly horizontal with lots of variation near the inlets and exits. Center: Mark I, option 9--There is one small inlet at the left and one small exit at the right. Although there are significant concentration gradients at the inlet, the contours show basically vertical profiles from left (inlet) to right (exit). Right: Mark II, option 2--There is a large inlet at the left bottom and a large outlet at the right bottom so that the flow makes a path that looks like an inverted U. The isoconcentration profiles show much more nonuniformity compared with those of the other chambers. The fluid traveling along the outermost edge of the U-shaped path has a long residence time in comparison to that along the inner edge of the path. Consequently, the isoconcentration contours somewhat resemble bicycle spokes emanating from the inner edge of the path.

Three CSC designs were assessed from the standpoint of providing uniform concentration fields while minimizing fluid-induced shear stress. All three designs share the same footprint but vary in flow path, membrane design, and inlet/exit geometry. All were examined with the same net flow throughput, with and without stirring. For the Mark I, option 1 design (left figure), two inlet ports exhaust directly into the bottom and center of the chamber. Fluid must pass through a membrane situated above the inlets around the periphery of the chamber in order to reach the two exit ports at the left and right sides of the chamber. The Mark I, option 9 design (center figure) has one inlet at the left and one outlet at the right. Fluid must pass through a filter both exiting and leaving the chamber. In the Mark II, option 2 design (right figure), inlet and outlet ports are attached to a plenum to reduce flow velocities in the chamber. Membranes are located between the plenum and the interior of the chamber. Since the ports are located on the same side of the CSC, the fluid path forms an inverted U, as seen in the figure on the right.

Using the ground-based protocols developed for yeast, flow visualization and dye concentration measurements were performed by Payload Systems, Inc., and numerical simulations were developed by Glenn. The numerical and experimental results were found to be in close agreement.

The isoconcentration contours in the figures show the resulting concentration field for all three chambers at a net flow rate of 0.9 ml/min and no stirring. These qualitatively match the fronts seen in the flow visualization as dye is introduced. For the Mark I, option 1 design, hemispherical contours around the inlets are apparent since the flow is not smoothed out by filter membranes, but rather exhausts directly into the chamber. If the inlets and outlets were on opposite sides of the chamber, the concentration contours would more closely resemble horizontal lines across the chamber. Although there are significant concentration gradients at the inlet of the Mark I, option 9 design, the contours show basically vertical profiles, indicating essentially unidirectional flow across the chamber. This is responsible for the high-quality flushing efficiency of this chamber observed in the flow visualization studies. There are substantial concentration gradients and nonuniformities in the Mark II, option 2 design because of the curved flow path from the inlet to the exit. Numerical analysis of velocity fields created by rotating stir bars (not shown) indicated that the most efficient mixing occurs in the Mark I, option 9 design.

As a result of this collaboration, the Mark I, option 9 design was chosen as the basis for the CSC. Current work involves improving the inlet design to enhance uniformity in the chamber as well as optimizing the stirring and perfusion protocols for spaceflight.

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