4-2-2012

Bubbles, Drops, and Streams: A Flow Visualization Cell

Said Shakerin
University of the Pacific, sshakerin@pacific.edu

FINAL REPORT

University of the Pacific
Scholarly/Artistic Activity Grant (SAAG) Report

Project Title: **Bubbles, Drops, and Streams: A Flow Visualization Cell**

Principal Investigator: Said Shakerin

Amount Funded: $1,500.00 (amount requested: $2,415)

Funding Date: 14 April 2011

Final Report Due Date: 14 April 2012

Date of Project Completion: 2 April 2012

Contents: Page #

Summary of Completed Activity

The goal of this activity was to develop an interactive flow visualization cell to demonstrate dynamic interaction between two fluids, olive oil and air, each occupying one half of the cell. The goal was met and a museum-quality unit was created as shown in Figure 1. Thanks to Dean Brigid Welch's support, the unit is installed at the University Library next to the Information Commons for the campus community to enjoy the inherent beauty and appreciate complexity of fluid flow.

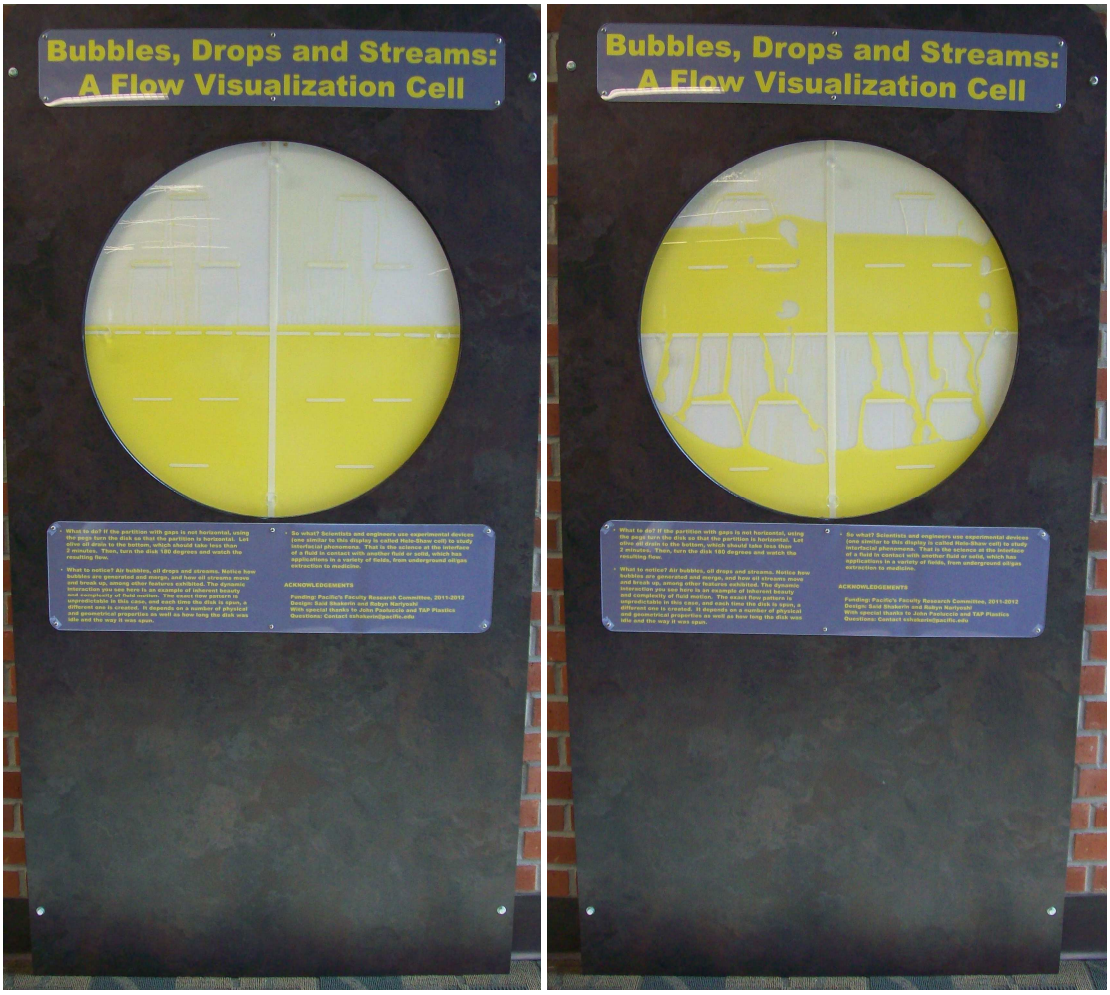

Figure 1 – The installed flow visualization cell. Overall frame size: 78 x 40 x 2 inches. Materials used for the cell (diameter = 30 inches): acrylic, 1/8 inch white back disk, ¼ inch clear front disk, 1/16 inch white ring between the back and front. Brief notes affixed to the frame inform users how to use the cell and outline its significance.

The cell is made of two acrylic disks that are separated by a thin acrylic ring and glued together. A vertical bar divides the cell into two separate semi-circular sections. In each section, a horizontal partition divides that section into upper and lower chambers. Each partition has five ¼ inch openings, which allow for the transfer of oil and air between the chambers. Normally, oil (the heavier fluid) rests in the lower chamber and air fills the upper chamber (left photo above). Once the cell is rotated one half turn, the oil is situated above the air, which is an unstable condition that results in oil to flow down and air to flow up (right photo above). It takes about 2 minutes for this opposing flow of oil and air to come to rest. The exact details of the flow are unpredictable. In other words, each time the cell is rotated, a new flow pattern is created. The underlying physics of fluids are rather complex in this case but suffice to say that the resulting flow pattern is caused by gravity, surface tension, and viscous force in addition to geometrical conditions and how the cell was turned. For a public display that is safe to operate, the cell is protected in a frame that stands on the floor and secured to the wall. A turntable is incorporated in the frame to allow easy turning of the cell, and a trough is placed underneath the cell (within the frame) to catch drips should the disk leak. The final frame design was arrived at after considering four

alternatives and consulting with an architect experienced in museum design. Four small knobs glued to the cell allow a user to grab and turn the cell.

The activity was accomplished in two phases. During phase one, June 2011-January 2012, eight preliminary flow visualization cells were designed, constructed, and tested to determine necessary details for completing the final design. (These followed up on what was learned in an undergraduate research study by Robyn Nariyoshi under the author supervision in 2010.) Figures 2-4 in the Appendix show examples of flow patterns created by some of the preliminary cells. The second phase, January-March 2012, involved fabrication of the cell, testing, and fabrication of its frame. Support Services/Physical Plant installed the completed unit.

The preliminary cells were fabricated by the author out of scraps left from previous projects as well as newly purchased acrylic sheet stock. Several variables such as cell size, material thickness, partition material and arrangement were tested and the results were used to inform the final design. Two unexpected and undesirable issues with respect to larger cells (more than 12 inches on one side) were discovered, and methods to alleviate them in the final design were devised. For example, not enough time was available to apply adequate amount of acrylic cement (glue) to surfaces because the working time is very short before the cement hardens. The solution was to divide the back cover of the cell into sections and cement one section at a time, thereby having more time to apply adequate amount of cement on a given surface. There was also a problem of creating partial vacuum when the oil flowed down once the cells were turned upside down which caused the front and back covers to bow in and touch each other, affecting the flow interaction. This problem was solved by adding small spacers at several places between the two covers to maintain spacing. In the final design, there are three spacers in two rows in each chamber; therefore, a total of 12 spacers are in the cell. Designed by the author, TAP Plastics of Stockton fabricated the cell and John Paoluccio fabricated the frame; both gave generous discounts, which enabled completion within the budget.

Expenses

Below, is a summary of expenses. Detailed itemized lists with receipts have been submitted to Ms. Deborah Burdick, School of Engineering & Computer Science, for reimbursement.

Item	Date	Amount ($)	Notes
Fabrication, 12-in cell	June 2011	100.00	TAP Plastics gave discount
Materials and Supplies	June 2011 – March 2012	523.00	Acrylic sheet stock and supplies (cement, glue, cutter, etc.)
Fabrication, 30-in cell	February 2012	350.00	TAP Plastics gave discount
Fabrication, Frame	March 2012	527.00	J. Paoluccio gave discount
Installation	March 2012	?	Paid by Library Dean
Total		**1,500**	

Anticipated Presentation and Publication

The flow visualization cell is on display at the Library for use by the campus community and visitors for a period of 6-12 months. A poster presentation is planned at the Gallery of Fluid Motion sponsored by the American Physical Society - Division of Fluid Dynamics at its annual meeting in November 2012. A paper will be written and submitted to a journal (e.g., Leonardo or Mechanical Engineering).

Intellectual Property

To the author's knowledge, it is the first time that a flow visualization as documented in this report is created for public display. Therefore, it may merit patent consideration. However, the author has no financial resource necessary for pursuing patent application.

Appendix – Preliminary Cells

Eight preliminary cells were designed and tested. Sample photographs depicting oil-air flows in four of the preliminary cells are documented here. Pertinent information is provided below each figure caption.

Figure 2 – Preliminary cell # 1.

Size = 3ft x 18in, Spacing = 1/16in (rubber gasket)

Construction: Acrylic plates were held together with two pairs of wooden bars and clamped with 24 spring clips. Two rows of partitions made of rubber gasket, with gaps of about 1/4in.

Outcome: Nice patterns created but the unit leaked badly and partitions moved. Partitions have to be glued to stay in place as clamping was not strong; therefore, the idea of a reusable unit is not practical.

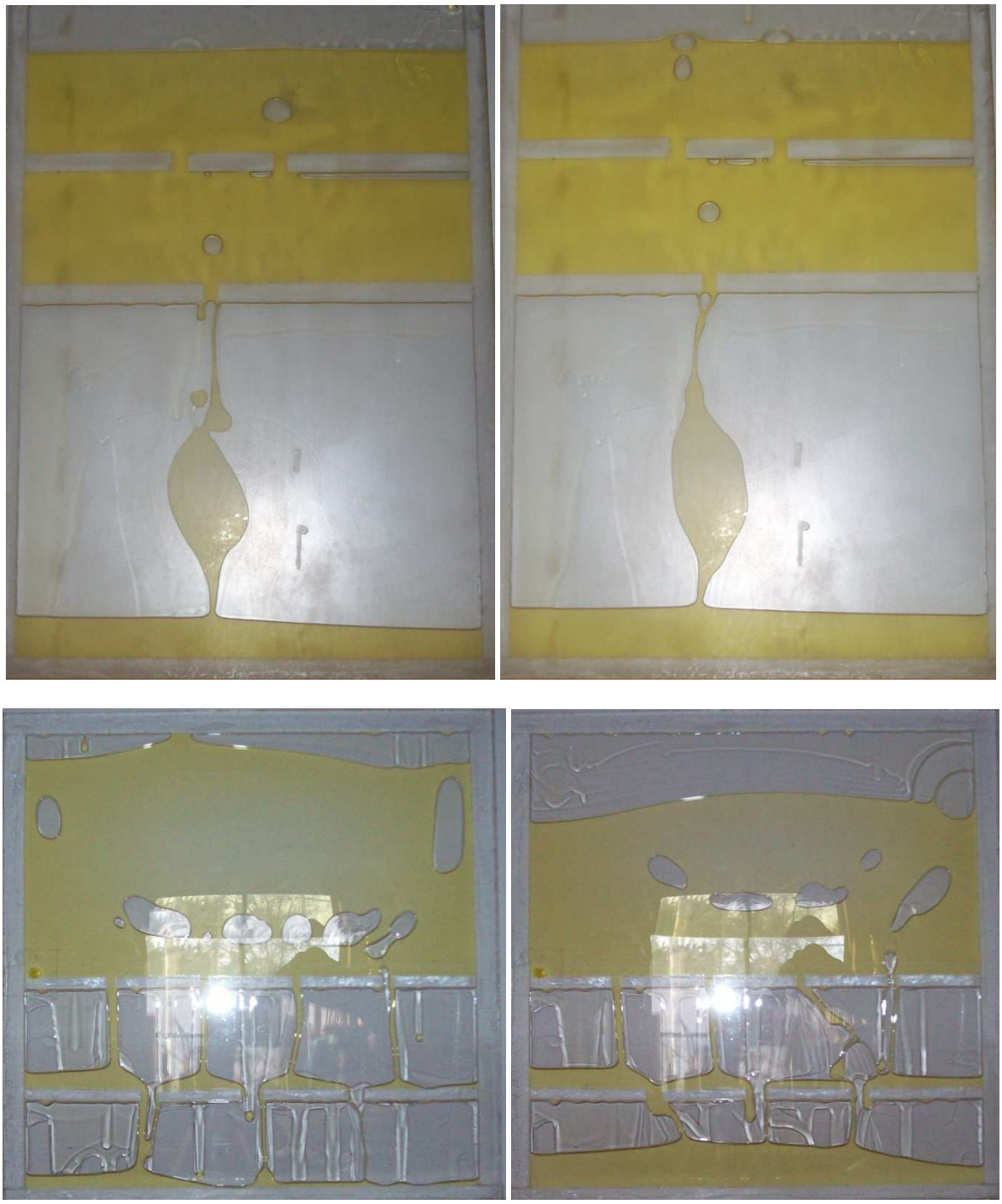

Figure 3 – Preliminary cells # 2 and 3 (top 18in x 12in, bottom 12in x 12in). Spacing is 1/16in and various partition arrangements were tested. Gaps in partitions are about 1/4in. Pieces are glued together. The segmented row under the central partition adds to the flow pattern.

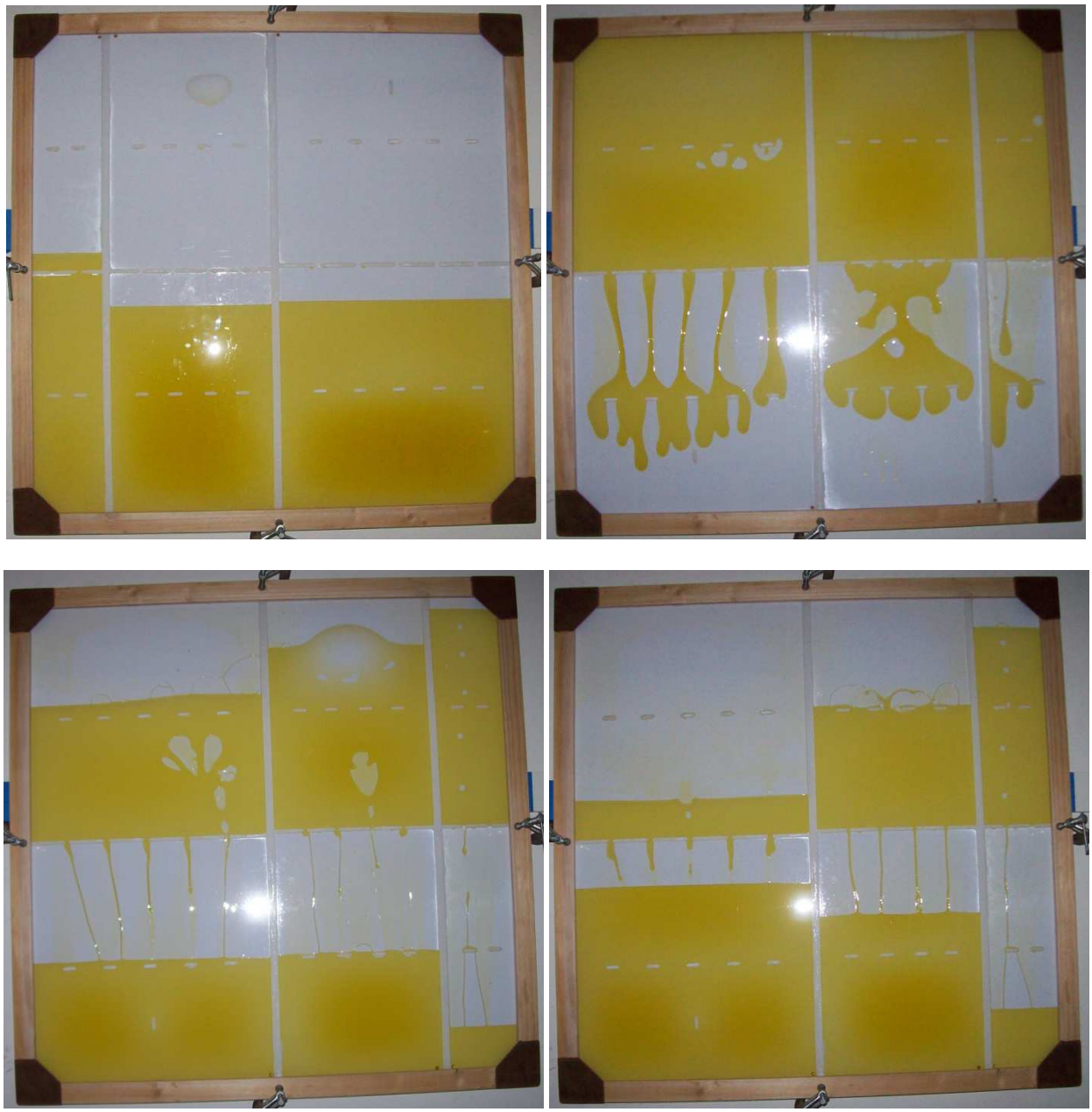

Figure 4 – Preliminary cell #8.

Size = 3ft x 3ft, 1/8in thick acrylic (white in the back, clear in the front), Spacing = 1/16in

Construction: Three separate chambers (widths = 6 in, 12in, and 18in) to test partition size and arrangement. One row of spacer blocks below and one above the central partition. The frame was made of 2 x 1 pine bars. Incorporated a lazy susan into the frame to allow easy rotation and utilized French cleat system to hang the frame on the wall.

Outcome: The front and back plates bow in as the unit is rotated because of large area and thin material (1/8in thickness). This is caused by partial vacuum created in the upper part as oil flows down and is indicated by the faint yellow color dome region shown in the left photo bottom row. As a result it takes a long time for the oil to drain into the lower section, about 10 minutes. Need to use thicker plates and include more spacer blocks to prevent bowing.