AC 2011-1889: FLUID DYNAMICS ART EXPLORATION: AN UNDERGRADUATE RESEARCH COURSE

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Fluid Dynamics Art Exploration: An Undergraduate Research Course

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This paper is dedicated to Itsuo Sakane, prominent author and chief curator of exhibitions interfacing arts, sciences, and human perception.

Abstract

A unique undergraduate research course is reported here. The course was created for a student to explore the fertile field that interfaces fluid dynamics and art. The course encompassed several components including creation of visually engaging objects utilizing fluid motion as a central theme. In this paper, the course structure and content are outlined, followed by description of three projects to illustrate how interested students can create objects that aesthetically showcase fluids-related phenomena. The objects produced via these projects are suitable as demonstration tools in informal science education, and they can be easily replicated with a budget of $400 at other institutions.

The first project was to create ten distinct flow visualization photographs using safe household fluids and simple setups. In the second project, an interactive device was developed with which granular (sand) flow is demonstrated in a fun and mesmerizing manner. For the third project, a series of modified Hele-Shaw cells were developed that exhibit the interaction between air bubbles and a viscous liquid (olive oil) in a museum-quality display.

Introduction

This paper is a documentation of an undergraduate research course S. Shakerin designed for R. A. Nariyoshi, who was a senior mechanical engineering student in the Spring Semester 2010 when she took the course. Both authors have been interested in merging engineering and art. The course provided an opportunity for the student, who is a dancer and choreographer and is specifically interested in movement studies, to explore the interface of art and fluid dynamics. Some general and review materials are presented below prior to the specific course documentation.

Most people consider artists and scientists as dissimilar groups. The latter is associated with mathematics and logic while the former is associated with feelings and emotion. Although these associations are true, some people have argued about similarities between the fields of art and science. Their efforts have been documented in books,[1-3] presentations at conferences,[4,5] and performances at exhibitions.[6,7] If we consider that artists express the world around them through their arts, and that scientists/engineers work to better understand, utilize, and shape the world around them, we then come to the conclusion that there ought to be some overlap between the two seemingly divergent groups. Indeed, before the advent of technology, many artists were also seekers of the laws of nature, i.e., they were also scientists/engineers. The best example is Leonardo da Vinci (1452-1519), whose meticulous scientific exploration and artistic work we can witness via his notebooks and paintings, which have appeared in many publications over the years.[8,9] With advances in technology barriers were created that separated the practitioners in the sciences from those in the arts.

Beginning in the 1960s, several notable scientists formalized their instincts about connection of and similarity between art and science by creating publications and establishing museums to promote works of art with strong scientific themes and content. As a result of their pioneering work the perception that art and science are dissimilar and not connected fields was at least partially dismissed. For example, Frank Malina (1912-1981), a distinguished aerospace scientist, founded Leonardo Journal[10] in 1968, which became the archival and leading publication for artworks created at the interface of science and art by artists, scientists, and engineers. Malina also left industry and devoted his life to kinetic art. Today, there are many kinetic artists who use a wide variety of materials and processes to create artworks many of which bring together artistic talent and scientific approach and knowledge. Another pioneer was Frank Oppenheimer (1912-1985), a brilliant physicist who was under-valued as a victim of McCarthyism. In 1969 he founded the world-renowned Exploratorium in San Francisco, which intertwines art and science.[11]

Three organizations that promote integration of art and science are listed here as examples.[12] In 1988, Art & Science Collaborations, Inc. (ASCI) was established to raise public awareness and promote collaboration among artists and scientists. The International Society of the Arts, Mathematics, and Architecture (ISAMA) has a periodic publication titled HYPERSEEING, which includes the annual proceedings of its interdisciplinary conference. The International Society for the Arts, Sciences, and Technology (ISAST) publishes several journals including Leonardo.

Specific to the title of this paper, there has been an increasing awareness about interactions of fluid motion and art in the last four decades. This is in large part due to the publication of An Album of Fluid Motion[13] in 1974 by Milton Van Dyke (1922-2010), and the establishment of Gallery of Fluid Motion, which has been sponsored by the Division of Fluid Dynamics of the American Physical Society since 1985 annually. An Album of Fluid Motion has been a source of inspiration to generations of students and researches in fluid dynamics. It is a compilation of hundreds of black and white photographs of numerous fluid flows visualized by a variety of techniques. Gallery of Fluid Motion is an exhibition of still images and short videos of flow visualization studies that not only look into physics of fluid flow but also display artistic values. A panel of experts selects the best of entries each year and the winners are published in the September issue of *Physics of Fluids* in the following year. An online archive of the winning entries and a compilation of those from 1985-2002 in a book form are available.[14,15]

More recently, several fluid mechanics educators have promoted the integration of fluid dynamics and art by developing specific courses, writing papers and presenting at conferences. Three examples are given here. Jean Hertzberg collaborated with a colleague from the arts department (at University of Colorado-Boulder) and developed a course titled Art and Physics of Fluid Flow. This course has been offered as an elective since 2003 and remains popular among students from engineering and fine arts. Details of the course and examples of student works have been documented and some have won awards at the Gallery of Fluid Motion.[16-19]

Gary Settles (at Pennsylvania State University) has, through his talks and publications, shared his experience about integration of fluid dynamics and art and encouraged others to embark on this integration.[20,21] An expert in high speed flows he is also a self-taught painter whose paintings take on the subject of fluid dynamics. An example of his painting is shown in Figure 1. This surrealist painting portrays many aspects of fluid flow in a symbolic and inclusive manner. It conveys an enormous amount of information about fluid dynamics in artistically rendered fashion. The flight of an egret whose foot is dragged in water creating waves on one side, and the flame of a candle on a cake resembling the vortical flow in Jupiter's atmosphere, on the other hand, is a testimony to the complexity yet inherently beautiful nature of fluid flows. The background is an iconic grouping of a variety of topics directly or indirectly related to fluid dynamics.

Figure 1 – "Fluid Dynamics - an Oil Painting," oil on canvas, 20" x 24", by G. S. Settles, 2006. (with permission)

Said Shakerin (at the University of the Pacific) has used water fountains with special effects as a medium to inspire his students to use fluid dynamics in creating artistic projects.[22-25] Such water fountains, which were made possible by advances in computer control technology, have become popular in the last 25 years in theme parks, resorts, and city centers. Amazing choreographed water shows, enhanced by music and light, can now be seen in cities such as Las Vegas, Shanghai, Dubai, and elsewhere across the globe.

Artists have also been inspired by the inherent beauty of fluid motion and have created works of art in which fluid behavior is the central theme and attention. Two examples are given here to illustrate artistic achievements. A recent work by William Pye is a 6-ft diameter whirlpool designed for a luxury hotel and is shown in Figure 2. The water is pumped and fills a specially made clear plastic cylinder while creating an air-core vortex at the center, and this takes 5 minutes. The pump is then switched off and the water drains out in 10 minutes after which the 15-minute cycle is repeated.

Figure 2 – "Charybdis" at Seaham Hall, Sunderland, England by William Pye, 2000. (Permission granted, artist website: www.williampye.com.)

Artist M. Maridakis in collaboration with fluid dynamics research team of A. Garcia and J. M. Chomaz created a spectacular large water sheet by two impinging water jets as shown in Figure 3. Each jet has a diameter of 1-9/16th in (4 cm) and flow rate of 100 gpm (22.6 m^3/h).

Figure 3 – "Aquatic Encounters" in Baune, Burgundy, France by M. Maridakis, A. Garcia, and J. M. Chomaz, 1999; close up of water sheet is shown in the right photo. (Permission granted.)

Course Content and Structure

At the University of the Pacific, academically strong students are encouraged to take an undergraduate research course as one of their electives. Typically, the interested student and the course adviser meet to discuss the scope and details. They complete and sign a one-page form that documents course objectives, requirements, expected outcomes, and other pertinent information. This form must be approved by the department chairman before student can register for the course.

Being a dancer and choreographer, the student expressed interest in combining her engineering knowledge with her artistic talent specially in expressing motion for this elective course. Thus, the objective of the course was to create visually engaging objects with fluid motion as a central theme. A list of potential projects was offered to the student to select four to explore and complete during the course. To further enrich the learning experience, three relevant books were assigned to be reviewed from a list of five.[13, 26-29] A one-page review was required for each book. Other requirements included weekly meetings with the adviser, written one-page weekly reports, final report, and presentation at a campus-wide research symposium held at the end of the semester. At the beginning, the student was encouraged to submit an internal proposal for funding, which was done, and funds were granted by the Graduate School towards materials needed for the projects. Furthermore, a museum visit was encouraged and the student visited the Exploratorium. Pre and post narratives of what was expected and achieved were also assigned. The course had 3 credits as an engineering elective, and was taken and completed in the Spring Semester 2010. The projects are described in the next section.

Projects

Four projects were selected by the student from a list provided by the adviser, but only three were completed due to time limitation. The expectation was to balance the time spent on research aspect with that on development such that visually engaging products would be completed by the end of the course. An ancillary objective was to use the produced objects as demonstration tools for informal science education that we provide to our students as well as university visitors such as younger students.

Project # 1 - Flow Visualization

Inspired by the Art and Physics of Fluid Flow course mentioned earlier,[16] the objective was to create 10 flow visualization scenarios and to document in still images. The requirements were to use a variety of safe household fluids, simple setups, and an ordinary (inexpensive) camera. The instruction was to create low Reynolds number flow situations with striking photographic composition. The cost of this project was negligible, as most of the materials were already available. All setups and photography took place at the student’s apartment. Several hundred images were recorded and 10 were selected by the student as the final outcome of this project. Five examples are presented below with associated photographs in Figures 4-8. While each photograph was cropped to highlight the flow being visualized, no digital alterations were made.

Figure 4 shows a stream of honey at room temperature as being drizzled in a jar filled with tap (cold) water. Honey has a higher density than water but on the same order, while it has a viscosity three orders of magnitude higher. The disparity in viscosity and the fact that it takes time for honey to dissolve result in unusual turns and twists in the drizzling honey stream as it sinks in the water.

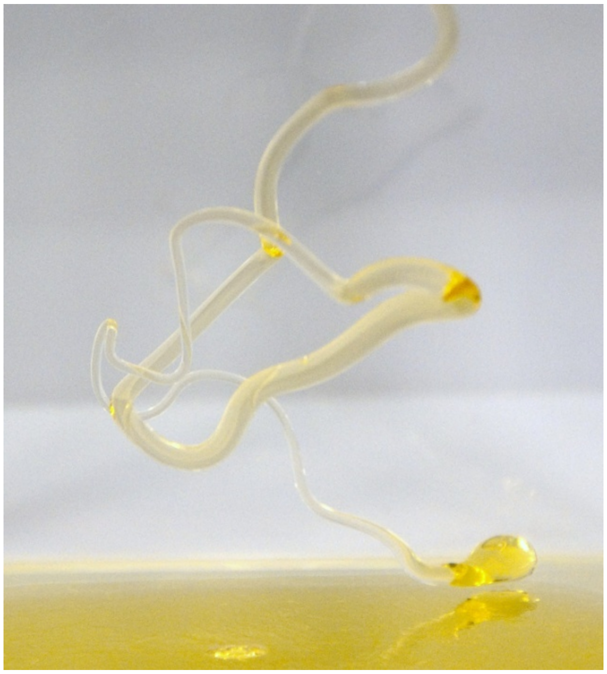

Figure 4 – Honey drizzled in water.

A small piece of dry ice held in a tong, as shown in Figure 5, produces descending CO_2 vapor that shows slight transition from laminar regime due to air motion in its surroundings. Another interesting feature in the image is condensation of water vapor on the tips of the lower prongs.

Figure 5 – Vaporized CO_2 flows downward from a piece of dry ice.

In Figure 6 a freshly drawn heart on a paper is being washed over by a falling water jet from a faucet. Several fluid dynamics features shown are chain links in the jet, circular hydraulic jump, waves, and small color mixing, which are all topics of contemporary research.

Figure 6 – Water jet washes over a heart.

Dye flow visualization is an old but effective technique still in use today. As shown in Figure 7, drops of blue food coloring were added to a freshly cracked egg to create an abstract painting. To add to the visual effect, the yolk was pierced with a needle just prior to adding drops. Color mixing took place as the yolk oozed out of its sack.

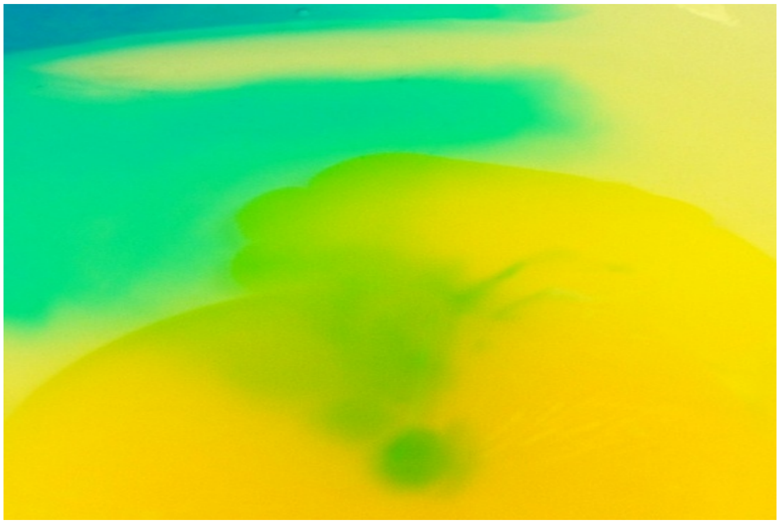

Figure 7 – Food coloring in cracked egg.

Drop impact (splashing) has been studied by generations of researchers, starting with the classic work of Worthington[30] in 1908 and continuing on today.[31] Drop impacts are also used by artists to create amazing images; one example is "Liquid Sculpture" by Martin Waugh.[32] In our case, a water drop's impact on a layer of water over a CD was recorded as shown in Figure 8. Notable features are a crater at the impact site, droplet rebound, satellite droplet, and waves generated around the crater. Rainbow colors produced by light diffraction over the CD add to the visual impact.

Figure 8 – Water drop impinging on a shallow pool of water over a CD.

Project # 2 – Hand-Held Sand Device

This project was inspired by the artwork of artist Ned Kahn[33] who creates museum-quality installations both indoors and outdoors that highlight scientific principles in an artistic manner. The objective of this project was to create an interactive device using a granular material to create 3-D surfaces. Granular flow is an important and active area of research.[34]

The project's research component included experimentation with different materials and design of a suitable container to hold the material. While sugar, table salt, and sand were tested, fine-grade sand was selected as the material of choice because it did not lump as other materials did after being exposed to air for some time. The final design for the container, shown in Figure 9, is a transparent Plexiglas cylinder assembled from two segments and a stencil disk in the middle, which could be easily changed. The lower segment serves as a base while the upper one holds the sand. The three small blue tabs keep the segments together and aligned. Each stencil has a specific design pattern represented by a series of holes to allow passage of sand as it is poured over the stencil. The hole patterns were drawn with a CAD software and a template was printed that was attached on thin Plexiglas disks (with double sided tape) and then drilled to ensure uniformity and alignment of holes. Several stencils and sets of cylinders were fabricated in the department's manufacturing facility. The cost for this project was about $50.

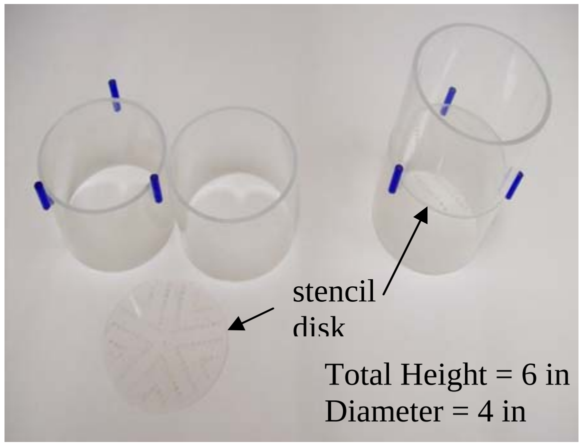

Figure 9 – Hand-held sand device, disassembled (left), assembled (right).

Figure 10 shows two snapshots after a cup of sand was poured over the stencil. A dynamic topography is formed above the stencil as the sand flows down and passes through the stencil. This dynamic show is further enhanced because the sand grains come in several shade of colors and their motion is mesmerizing to watch.

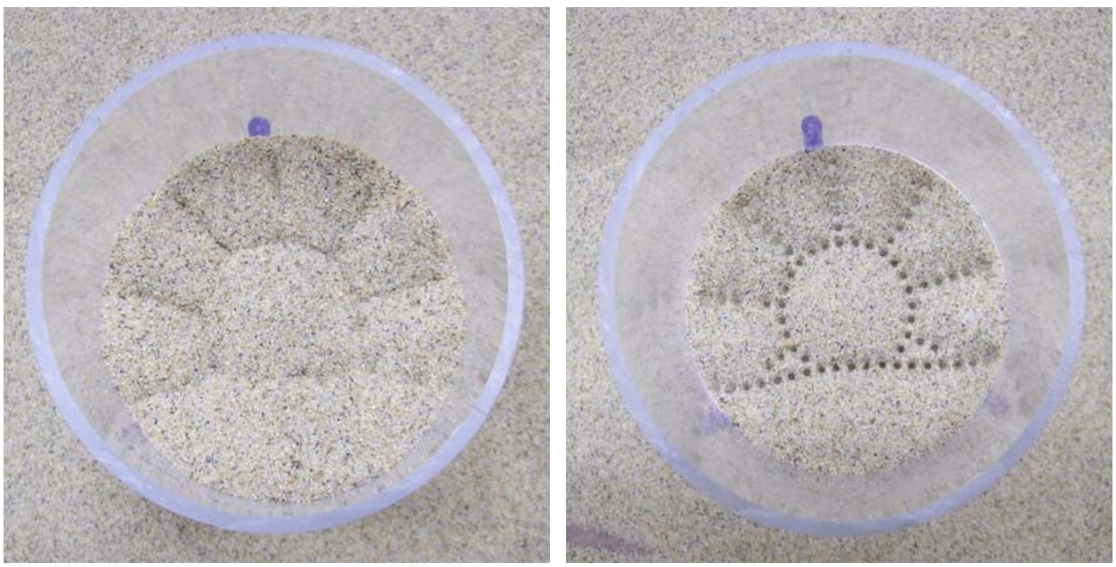

Figure 10 – Sand flow creating 3-D surface seen at two different times, early (left), later (right).

Project # 3 – Modified Hele-Shaw Cell

The inspiration for this project came from science-based displays at Exploratorium and the vinegar-olive oil appetizer served in some Italian styled restaurants. The objective was to create a museum-quality desktop unit to exhibit interaction of two immiscible fluids. A two-dimensional flow situation was selected to keep the weight of the unit to a minimum, namely flow in a Hele-Shaw cell (HSC). HSC was devised by Henry S. Hele-Shaw (1854-1941) in the late 1890s as a means for investigating flows in thin cells.[35] The use of HSC as a research tool has continued to the present time.[36]

Initially, three makeshift rectangular HSC, made of two 5 in x 8 in x ¼-in thick Plexiglas plates separated by a 1/16-in rubber gasket and held together with 8 medium size spring clips, were used to investigate the flow interaction between different fluids. Three fluid combinations were examined, namely vinegar-olive oil, water-olive oil, and air-olive oil. The last combination (air-olive oil) was selected as the final choice because it produced the most interesting visual effect as air bubbles moved through oil. The air bubbles in a HSC are flattened and hence easily seen.

A modification was made to the HSC. A partition with a central gap was made of the same gasket material and inserted in the cell, thereby dividing the cell into two equal chambers. The partition gap plays a central role in the nature of flow when the cell is rotated 180^o so that oil is positioned in the upper chamber. If the gap is small, for example 1/8-in or smaller, nothing happens because oil surface tension prevents its flow from the upper chamber into the lower. If the gap is large, for example ½-in or larger, then oil flows down and air flows up at the same time as expected. However, for a small range of gap sizes of about ¼-in a rhythmic flow is the result – the air bubble upward flow is alternated with the oil drop/blob downward flow. A relevant scientific investigation that examined the effect of opening size on the discharged flow from a water bottle also showed a rhythmic flow regime of air bubbles and water for an intermediate range of opening sizes.[37]

For the final unit, a circular 12-in diameter (3/8-in thick) modified HSC was then designed to hold air and olive oil in equal volumes, see Figure 11. The gap in the partition (1/16-in thick) is ¼-in wide, allowing the rhythmic flow regime when the cell is inverted. A separate base/stand was designed to hold the cell in the vertical position while allowing for easy rotation of the cell. The cell, partition, and stand are Plexiglas. A filling hole (1/4-in diameter) in one wall of the cell allows for injecting oil with a syringe; the hole is sealed with a cork. The cell's CAD drawings were taken to a local plastic shop (TAP Plastics) for fabrication. Most of the budget was used for this project (about $100 per modified HSC for materials and fabrication).

Figure 11 – Modified HSC with one gap in partition and stand. Note the small cork on the top.

Figure 12 shows two instances of the rhythmic interaction between air bubbles and oil flow in the modified HSC. It usually takes about 10 minutes for olive oil to completely drain into the lower chamber.

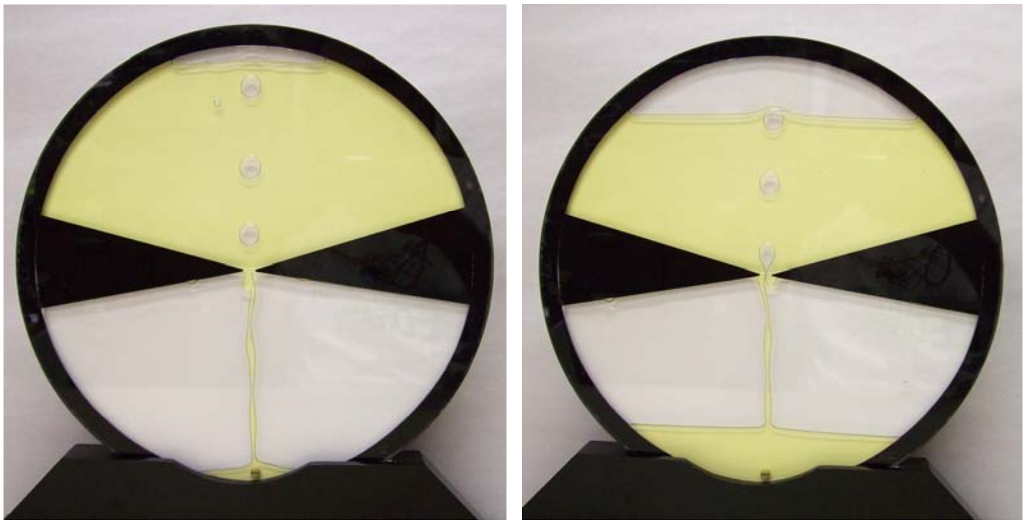

Figure 12 – Air bubbles and oil flow interaction in modified HSC with one gap in the partition.

Other versions of the modified HSC were also fabricated in which the partition had more than one gap. An example is shown in Figure 13 where the partition has three ¼-in gaps.

Figure 13 – Modified HSC with three gaps in the partition.

When this version of modified HSC is inverted, interesting interactions take place as shown in the two pictures selected for Figure 14; noteworthy among them are:

1. Air bubbles are formed at different gaps, which sometimes switch. Note the air bubbles rise from the center gap in Figure 14A and from the left gap in Figure 14B.
2. In Figure 14B, the lower bubble is just merging with the upper one.
3. Air pockets are formed between oil streams flowing down into the lower chamber. As necessary for pressure equalization, streams undergo fluctuations and break down frequently, e.g., see the left stream in Figure 14A.
4. Air bubbles rise through the oil and reach the top surface; they linger around for a while and expand as other bubbles reach underneath and form nested domes before bursting. This can be seen in both pictures.

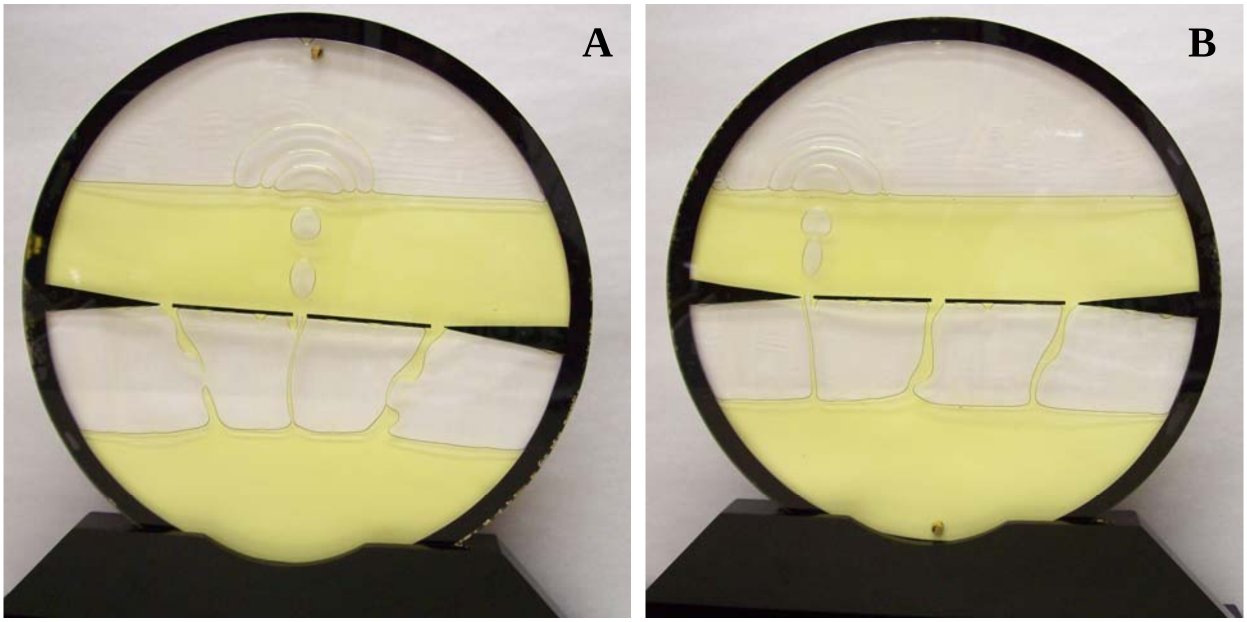

Figure 14 – Air bubbles and oil interaction in modified HSC with three gaps in the partition.

It should be noted that each time the modified HSC is operated the resulting flow interaction is unique, which depends on the idle time since its previous operation and how fast it is rotated. The flow uniqueness and the range of phenomena outlined above add to the attractiveness of the modified HSC in exhibiting the complexity and beauty of air-olive oil flow interaction. It takes about 2 minutes for the oil to completely drain into the lower chamber, providing enough time for the user to appreciate the flow.

Summary

A research course, integrating fluid dynamics and art, was developed for an undergraduate engineering student-dancer. The research and development in creating flow visualization photographs, hand-held sand device, and modified Hele-Shaw cells, and other assignments provided a unique learning opportunity for the student to exercise her creativity and engineering knowledge to produce high-quality products. The emphasis was on creating visually engaging and artistic 2- and 3-dimensional products with fluid motion as the central theme. However, specific engineering educational aspects of the course included setups and devising procedures to conduct experimentations required to accomplish each of the projects, design and fabrication of the products, proposal and report writing, and presentation.

The products resulting from this course were exhibited at a campus-wide research symposium. Furthermore, the products have been used as demonstration tools in informal science education activities. The audience responses to the exhibition and demonstrations have been positive and encouraging. Fluid Dynamics is indeed a “photogenic” subject as once noted by the editors of Journal of Fluid Mechanics in their review of the fluid dynamics film series produced in the late 1960s and early 1970s.[38] Future plans include developing large-scale versions of the sand device and modified Hele-Shaw cell for exhibition in campus buildings and wall installation.

Acknowledgments

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