The World of Soap Bubbles: From Fantasy to Science

Pallavi Ghalsasi[1*]

School of Science and Engineering, Navrachana University, Vasna-Bhayli Road, Vadodara- 391 410, Gujarat, India

Email: pallavi.teredesai@gmail.com, pallavig@nuv.ac.in

Abstract:

Soap bubbles have been one of the most fascinating play activities for almost every child. The various ways of making different size bubbles, their reproducible geometrical forms, their beautiful colours, and their tenacity, the emotional involvement in their sustainability before they perish and the way they fly, have always added to the cascaded excitement in the play with soap bubbles. It is not limited to just children but also has been of profound interest to poets, scientists, mathematicians, artists and architects for hundreds of years. Apart from the fantasy driving most of the innocent playful and dreamy minds, soap bubbles also display a plethora of deep science and a variety of forces shaping nature. Present article depicts a way to appreciate science through the lenses of multidisciplinary dimensions, the same manner in which the very Nature has unfolded it to us. The article then reviews enormous progress the human beings with curious minds have made to search for the origin of the observations pertaining to soap bubbles, either made casually or consciously. Although the article is based on various aspects of science of soap bubbles including some demonstrations, the approach can be extended to many topics in all the disciplines.

Keywords:

Soap bubbles, soft matter, interference, fluid mechanics, structures

Introduction:

For a very long time, various artists and poets have illustrated their paintings or poems themed around soap bubbles in Europe and America dated back in 16th century. As per the records of Roman historian Pliny the Elder, the physical properties of soap were known to mankind since 600 B.C. and soap was first invented by the Phonecians from ashes and goat's fat. The Saponification reaction was carried out by constantly mixing animal fats with continuous addition of ashes followed by boiling the mixture. By chemical splitting, the fatty acids in the animal fat react with the alkali carbonates contained in the ash giving 'soap' as the product [1].

In the present article, I will first explain various ways and tricks to make soap bubbles. The subsequent sections will take you through deep intricacies of the soap bubbles and the plethora of knowledge that one can gain from soap bubbles. This would definitely help in developing a sense of connectivity of soap bubbles to many open un-answered questions and hence their applications in science and technology. At the same time, a reader would realize that it is possible to remain poetic, dreamy and playful at heart and still be scientific in action!

The art of making soaps bubbles:

Soap bubbles can be made by any object that can hold a soap film. Most commonly used are small circular wire frames which can hold such soap films. After blowing air through such films, one can generate a series of almost uniform size bubbles. Small diameter drinking straws can also be used to make small and big bubbles. When a straw dipped in a tray containing soapy water is pulled out and air is blown through it, we get numerous bubbles. If a bubble is dropped on a wet surface, one can get a hemispherical bubble. By gently pulling out the straw, one can blow other small bubbles within the outer big bubbles. There are a number of innovative methods of making uniform size, long lasting, very big and very small size soap bubbles and giant soap films [2,3]. One needs to properly *zip* a soap film while blowing/entrapping air into it, which will result in bubble formation. Coloured bubbles can be made by adding phenolphthalein and changing pH with sodium hydroxide. When air is blown through a drinking straw dipped in a container having soap water, lots of bubbles coalesce with each other forming foam. Soap bubbles can also be frozen at extremely low temperatures around 9-10 deg F. It is a fun to watch the frozen bubbles cracking like an egg shell. Soap films generated on a variety of three dimensional frames as shown in figure 1, also demonstrate very consistent patterns pertaining to physical laws while maintaining minimal surface area.

It should be always remembered that the bubbles should never be touched with a dry hand or object. When a dry object touches a soap bubble, the bubble surface tries to stick the object which produces a strain on the bubble surface which results in bursting of the bubble. Other factors like evaporation of water in bubble and outside air turbulence also can make the bubbles unstable. However, they can be minimized by choosing proper conditions to begin the play.

If we do careful observation while blowing bubbles and films, certain questions tinkle in front of us like, why do the bubbles burst, how two bubbles coalesce, what shape does the common surface between two bubbles take, which shapes do the soap films make on geometric wire frames, how does your image look on the bubble surface, why brilliant colours are observed on the soap surface? A systematic study taken up to get answers to such questions is what leads to scientific understanding.

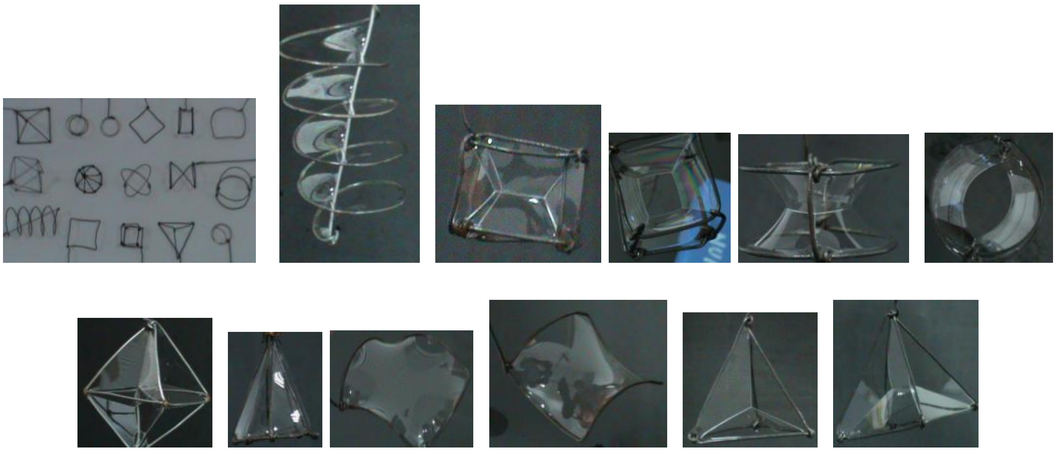

Figure 1: Soap films taking minimal surface area on various geometric wire frames

How does a soap film get formed?

Soap is made up of surfactant molecule which is typically, a long molecule having a hydrophobic tail and hydrophilic head. When surfactant molecules are dissolved in water, a bilayer is formed (figure 2) with heads facing the water layer and the hydrophobic tails hanging away from the soap film surface. Although soap film is made up of few molecular layers, the soap bubbles are extremely thin. Increasing the concentration of surfactant molecules facilitates forming bigger bubbles and also better foam.

All liquids do have a property called ‘surface tension’. Since the molecules in the outside layer of liquid experience unequal attractive forces which are less strong from air molecules on one side and stronger by liquid molecules within, the liquid layer appears to be stretched like a rubber sheet, which is called as surface tension.

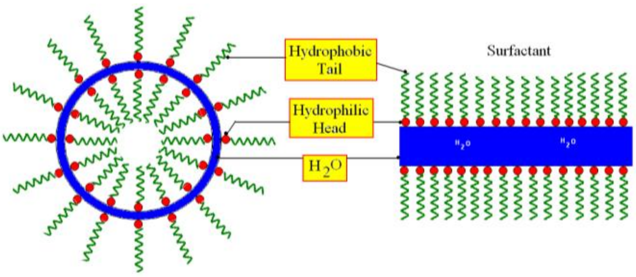

Figure 2: Surfactant Bilayer forming Soap Film

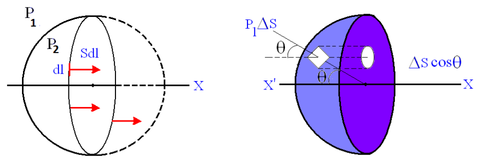

Figure 3: Forces acting on soap bubble

Water strider insects can easily walk on the water surface without sinking due to high surface tension of water. Also, a metal needle, can float on the surface of undisturbed water in spite of having more density than water. It is this property of surface tension of water that is used in making some of the tent materials rain proof. Marangoni effect demonstrates how strongly a liquid having high surface tension pulls its surround liquid towards itself as compared to the one with low surface tension.

Surface tension always tries to minimize the surface area of liquid. Due to this fact, always liquid droplets, bubbles form spherical surfaces. Across a curved surface of liquid, there is a discontinuity in pressure (P_2-P_1=4S/R), where, R is the radius of curvature of the surface, S is the surface tension and P_1 and P_2 are the pressures outside and inside the bubble respectively (figure 3). The smaller the drop, the greater is its internal pressure.

Optics with soap bubble:

Surface of soap bubbles is extremely smooth, shiny and 100% transparent, making them excellent natural mirrors. The spherical surface of a bubble has two sides and hence give rise to two reflections as shown in figure 4. The more distant side acts as a concave mirror which focuses an object into an inverted real image inside the bubble. Whereas the near face of the bubble acts like a convex mirror and the rays reflected from it appear to come from a virtual erect image. Since the hydrophilic polar heads of the surfactant molecules line up along the water film on the boundaries of the bubble. It would be worthwhile to observe the colours of the bubble through polarizing sheets. One can also observe ice crystals and birefringence effects on the freezing bubbles through polarized glasses .

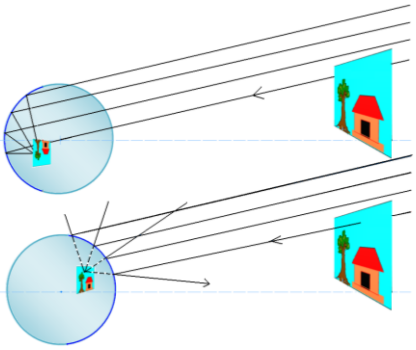

Figure 4: Double reflection from soap bubble

Figure 5: Interference on a Vertical Soap Film

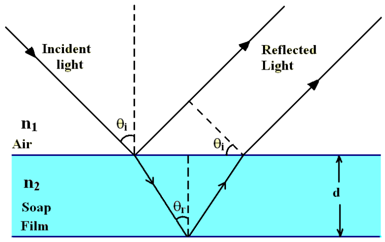

Figure 6:Thin Film interference

Apart from reflections, soap bubbles display brilliant colours as a result of thin film interference from their surface (figures 5 and 6). In 17th century, Sir Isaac Newton used soap bubbles to study interference of light and also a devised a method to measure thickness of the thin film showing interference.

Fluid Mechanics with soap bubbles:

Vertical soap films drain downwards due to gravity. This makes the upper part of the film have thickness lesser as compared to the lower part of the film. The draining effect also manifests in the interference pattern visible on the soap film giving rise to a number of horizontal interference bands (figure 5). In the limit when the thickness of the upper part of the film becomes smaller than the wavelength of visible light, no interference pattern is visible and the film looks perfectly transparent.

The interference bands seen on the soap film are quite sensitive to the perturbation. A slight blow of air around the film makes the pattern look turbulent. The manifestation of perturbation in the interference pattern gives soap films self visualization property. Hence they are considered as model systems for understanding two dimensional fluid flows and studying phase transition from laminar flow to turbulent flow [4].

Bubble Mechanics and Structures:

Like the bubbles can burst with slightest touch with dry objects or small perturbation, they also have a tendency to coalesce. It is interesting to watch how two bubbles join each other and study the nature of the common surface between the two bubbles. If the two bubbles are of the same size then the common surface between them is flat in nature. However, if one of bubbles is too big, the common surface has curvature and it is convex inside the bigger bubble. The curvature of the common surface depends upon the internal pressure difference between the two bubbles. Since the inner pressure is more for the smaller bubble as compared to the bugger one, the curved common surface looks convex within the big bubble.

Foam is another form of soap bubbles where many of them coalesce. The self assembly of soap bubbles always takes place in such a way that at a point, only three bubble walls meet along a line, separated by angles of 120°. Elastic substances under stress most efficiently fracture into hexagonal shapes as seen in variety of examples seen in Nature like stress lines found in rocks, dried mud, and cracked surface of an ancient Chinese vase [1,5]. This is the same reason why the cells of a beehive use the same 120° angle, thus forming hexagons. Snowflakes, plant and animal cells and the shells of tortoises, spots on ladybug shell, snake skin, central portion of trees, basalt rocks, melting butter and many such examples show single or repetitive hexagonal configurations.

Apart from three bubbles meeting each other, four bubble walls can also meet at a point, with the common lines making an angle of 109.47° leading to tetrahedral geometry [2,3]. The skeletons of many sea creatures do show similarities with bubbles. Foam has also inspired architects to imagine compartmentalized rooms. The minimal surface criteria displayed by soap bubble frames have also been used to find solutions to problems in designing structures.

Soap films have greatly helped in membrane analogy pioneered by Ludwig Prandtle while studying stress distribution in a long bar in tension. It turns out that the form of the differential equation governing stress distribution on the bar in torsion is the same as that governing the shape of a membrane under differential pressure. If a cut out from wood having same shape and size of the cross-section of the long bar is covered with a soap film and then is subjected to differential stress, the slope of the soap film at any area of the cross section is directly proportional to the stress in the bar at the same point on its cross section. Soap films can be formed to exhibit both anticlastic and synclastic curvatures. They have helped architects and engineers design unimaginable light weight flexible tensile tent structures [6].

Bubbles and Applications:

Keen interest is being taken in recent research in investigating bubbles in aqueous media as they are of pivotal importance in many biological, industrial and technological processes. Understanding of bubble growth, fusion, fission, coalescence and stability are the key areas while studying the bubbles. The presence/introduction of gas bubbles is found to be useful in many applications.

Bubble rafts are very useful to demonstrate and model {111} plane of a close-packed crystal which include, defects and dislocations and grain boundaries [7,8]. Due to their very low volume to surface ratio, they can also be used for sub-ppm level detection of gases [9]. Some studies on bubbles have been carried out related to dissolved gases in liquids [10]. Bubbles are of pivotal importance in the area of microfluidics [11,12].

Cell membrane of animal and plant cells is a complex and dynamic bilayer made up of lipids. Soap bubbles have striking similarity with cell membranes and hence the study of bubble dynamics will surely help dynamics of cell membranes.

Pulmonary surfactants play a crucial role in respiration process. These surfactants are lined along the air-liquid boundary of the alveoli. During inhalation, inflation of lungs requires an excess pressure inside the alveoli relative to outside air. Reduction of surface tension by pulmonary surfactants helps the alveoli inflate with even low pressure difference. They also help in elastic recovery of alveoli during exhalation. Thus bubble dynamics can help us understand about respiration related stress especially in newly born babies [13,14].

Bubbles are also being used successfully in complex medical surgeries. They are also being considered as means of efficient drug and gas delivery. Inventions in bubble packing materials are also growing.

Conclusion:

This article has tried to touch upon briefly the deep insights of science of soap bubbles encompassing diverse areas. The knowledge ocean and the practical applications of bubbles are growing exponentially. We must also admit the sheer joy while experimenting with bubbles and our involvement with them can seamlessly take us to the journey of digging deep science behind their unusual properties!

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