

POSSIBLE USE OF SURFACE TENSION TO SHAPE SPACE STRUCTURES

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Abstract

An argument is presented predicting the possibility of thick walled surface tension bubbles in zero gravity space. Liquid vapor pressure is suggested as the main factor limiting bubble size in space vacuum. The several orders of magnitude change in liquid vapor pressure near the freezing point make the expansion of large metallic bubbles possible at low temperatures while small bubble size at high temperature allows the heat separation of high and low vapor pressure materials in space vacuum. This makes possible the conversion of any space rock with metallic content into a thick walled metallic bubble by heating to a high temperature and inserting a gas producing pellet as it cools. The beneficial effects of these spheres in orbit near Venus is discussed. An ice cube in mercury experiment in space is recommended along with a computation to predict the size bubble the experiment will produce.

Shelter in Space

The number one technical problem the prehistoric human race had to solve, when it left the forgiving climate of the tropics and colonized the more hostile temperate and arctic zones, was the use of indigenous material to provide warmth and shelter. The mastery of the skin tent or the ice igloo made survival possible in the new land.

The use of surface tension to shape some of the millions of orbiting meteorites and asteroids, circulating our sun, into spherical pressure vessels could provide the space igloos that make the colonization of space possible.

In zero gravity, surface tension shapes a liquid into a sphere. The pressure shaping the sphere is proportional to the liquid surface tension T and inversely proportional to the sphere's radius r .

$$p=2T/r$$

The equation says, that small spheres squeeze harder than large spheres. This makes surface tension spheres intolerant of bulges. A small bulge in a large

sphere is squeezed harder than the large spherical surface it protrudes from, because it is treated as a part of a sphere with a smaller radius.

Space Bubble

The surface tension sphere's intolerance of bulges allows the improbable soap bubble to survive the forces of inertia, gravity, air turbulence and evaporation, all seeking to distort the spherical shape and weakens its thin walls. If an unworldly scientist had never seen nor heard of a soap bubble, it is unlikely that he would predict the possibility of its existence from theoretical considerations.

Nevertheless, let us try to predict the characteristics of a surface tension bubble in space, something that no one has ever seen. First, we must not confuse it with the glass blower bubble on Earth. If his leathery bubble begins to bulge, it is not surface tension but viscosity that is used to restore the bubble's shape. The glass blower cools to strengthen the glass by increasing its viscosity. He heats to reduce viscosity in areas he wishes to expand faster. He must work glass in this viscosity range, because on Earth, surface tension will not support the thick glass walls of the vessel he is shaping. No support problems exist in zero gravity space. We may produce surface tension bubbles in materials with the viscosity of water.

Wall thickness of the space bubble is one area where a theoretical prediction is necessary, until the first space bubble is observed. Uniform wall thickness would be nice for producing useful surface tension shaped vessels. Will a vapor sphere inside of a liquid sphere in space find its way to the center of the liquid sphere?

In gravity free space, where things stay put unless given a nudge, it is easy to picture an air bubble resting contentedly anywhere inside the liquid sphere. After all, the pressure surrounding the air bubble is the same at all points inside the liquid sphere.

Although a vapor bubble of a fixed size might reside anywhere inside a liquid sphere, I believe a growing vapor bubble would quickly seek and find the

liquid sphere's center. The vapor bubble must expand against the liquid's viscosity as well as its surface tension. Like the viscous glass blower's bubble, the expanding ball of vapor will find the weak spot in the surrounding liquid wall and begin to bulge. This will be at the thinnest spot in the liquid wall.

The space bubble, with the viscosity of water, however, will not respond to the bulge like the leathery viscous glass blower bubble. It will react like the soap bubble. Surface tension will squeeze more tightly on the bulge and cause expansion on the thick side of the liquid sphere. This will move the center of the gas bubble closer to the center of the liquid sphere. The only place where the gas sphere may expand without distortion is at the center of the liquid sphere. Here it will be at home.

Space Sphere

It is also necessary to predict the conditions under which liquid surface tension spheres may exist in the vacuum of space.

Liquid surface tension sphere should be able to exist, as long as surface tension pressure exceeds the vapor pressure of the liquid it contains. At this point the liquid will begin to boil in space as it would when on earth when the vapor pressure exceeded atmospheric pressure.

If we substitute vapor pressure in mm Hg for pressure in the surface tension equation and a factor of 1333 to convert this to dynes/sq cm, we get the radius in centimeters of the maximum size sphere that can be contained by surface tension for a vapor pressure p in m Hg.

$$r = 2T/(p*1333)$$

This quickly eliminates soap bubbles in space. The maximum size surface tension water sphere at 1 C°, minimum water vapor pressure, is:

$$r = 2*72/(5*1333) = .02 \text{ cm}$$

For mercury, one of the few liquids where vapor pressure data is available near the freezing point below 1 mm Hg, the results are more promising. The diameter in meters of the maximum mercury surface tension sphere, with a surface tension of 476 dynes/cm, is:

$$D = 2T/(p*1333*50) = .014/p$$

Temp C°	Vapor Pressure Hg mm Hg	Max. sphere D Meters
52	1.4×10^{-2}	1
22	1.4×10^{-3}	10
-2	1.4×10^{-4}	100
-22	1.4×10^{-5}	1,000
-38	1.4×10^{-6}	10,000

Space Vacuum Distillation

Although this places restrictions on the size vessel, that might be shaped by surface tension, it has a good side for constructing a space igloo. As will be illustrated later, a very small amount of trapped vapor can form a large bubble. If we try to remove the volatile material in a space rock, by heating it in the vacuum of space, we do not wish to end up with a misshapen ball of porous slag filled with bubbles of all sizes. On Earth, gas bubbles leave a molten crucible of steel because of the weight of metal. In gravity free space, this method of gas removal would be difficult. Will the same surface tension that allows us to shape vessels in space fight us when we attempt to refine the material of construction? This table indicates that the answer is probably "no." As we heat to remove unwanted gasses from the material, we wish to shape into a hollow sphere, we raise the vapor pressure. This reduces the size of the bubbles that may exist in the material that remains after the more volatile materials are driven off. At 200 C°, mercury has a maximum bubble size of:

$$D = .014/p = .014/17.21 = .0008 \text{ meters}$$

Without surface tension to fight the tendency of expanding gasses to find the weak spot in the containing liquid and escape, they will escape.

It is likely that this distillation process can take place in the vacuum of space. Simply raising the temperature of a space rock to a high enough value will cause the high vapor pressure components of the rock, that would make poor material for space bubble construction to depart, leaving behind the elements in the rock with the lowest vapor pressure. The lower the vapor pressure, the larger the surface tension bubble which may be constructed from the material.

At the end of the degassing process, the boiling mass of mostly metals will be held together by viscosity and gravitational forces. It will be a boiling liquid, misshapen by the degassing process. As it cools its vapor pressure will drop to a value that will again

allow surface tension to shape the liquid into a perfect sphere. At a properly selected point in the cooling process a pellet will be inserted into the sphere. The pellet will vaporize to provide the correct pressure and volume of gas to expand the liquid sphere as a bubble. The amount of gas will be calculated to produce walls with the thickness required by the finished vessel. After it cools, the space inside the sphere is shelter from the radiation of space and a pressure vessel to contain an atmosphere or more of pressure.

Venus As Location

It is likely that at some time in the future a spacecraft will have enough energy at its disposal to perform this transformation from space rock to a habitable hollow sphere. Engines that can accelerate material extracted from a space rock to adjust it's orbit are likely to become available first. The degassing process could take place by moving a space rock into an elliptic orbit that takes it near the Sun. The cooling hollow sphere could then be directed to its final orbit. This is not likely to be around the Earth, too dangerous. Mars would not welcome orbiting spheres that block rays from its dim Sun that and have an appetite for the gasses of its thin atmosphere. Those responsible for making Venus a more habitable place would accept these spheres with open arms. Their shadows and appetite for gasses would be welcome in a world of killing heat and crushing atmospheric pressure.

Enough objects in orbit between Venus and the Sun would do wonders for its environment. When the carbon dioxide atmosphere of Venus is cooled below 87°F, the liquid density of CO₂ becomes greater than the vapor density and the CO₂ rains begin. The atmospheric acid will be carried to the ground where it will react with the oxides of the soil and release water into the atmosphere. Unfortunately, no one will be swimming in the balmy 80 F° pools of liquid carbon dioxide. The atmospheric pressure will still be a crushing 1000 psi.

Water is unlikely to be more than .5% of the CO₂ rain. This is the ratio of the vapor pressure of H₂O to CO₂ at these conditions. The heavier H₂O will be lost in rivers and oceans of CO₂. However, at 32°F ice crystals should appear on the CO₂ lakes. This separation may allow puddles of water to exist, unfortunately at about 500 psi. CO₂ can no longer exist

as a liquid below 75 psi. At about -70°F all CO₂ on Venus turns to dry ice.

Although the use of surface tension spheres as sun blocks may not turn Venus into a habitable world, it is certainly a reasonable first step. These spheres need not be thick walled habitable spheres. We have no idea how thin a surface tension bubble may be produced in space. If a millionth of an inch wall thickness is possible, it would not take much material for a well placed bubble machine to cool Venus, or Earth if the greenhouse effect here becomes a problem.

Ice in Mercury Bubble

It is time to begin gathering experimental data on surface tension bubbles in space. A suitable experiment could utilize mercury and water ice. If an ice sphere of 1 cm radius (to simplify computation) is inserted into a sphere of mercury (as large as we wish), below a temperature of -13.7 C° nothing much happens. The pressure required to expand a bubble of 1 cm radius in mercury is:

$$p = 4T/(r*1333) = 4*467/1333 = 1.40 \text{ mm Hg}$$

A coefficient of 4 not 2 this time because we expand against two surface tension films, the inside and outside walls of the bubble.

If we heat the sphere to above -13.7 C° the vapor pressure of the ice will exceed 1.40 mm Hg and produce a bubble of 1 cm radius which will continue to expand. A larger bubble requires less pressure to expand. The vaporization of the ice, the expansion of the gas, the increase of surface energy of the bubble will all tend to cool the bubble and inhibit its rate of growth, but not enough to stop the expansion. After a doubling in size to 2 cm radius the bubble requires only .7 mm Hg to continue expansion. This is the vapor pressure of ice at -21 C°. The heat capacity of the mercury will prevent a 7 C° cooling.

Bubble Size Computation

The bubble will not expand forever, even though the surface tension bubble continues to push back with less pressure as it expands. If we assume a path of expansion, that will not happen in practice, we can compute the containment point where the bubble will stop expanding in an isothermal expansion.

First, we vaporize the one cm radius ice cube. The steam tables provide us with the ratio of volume of saturated vapor to solid ice at -13.7 C°:

$$V \text{ vapor}/V \text{ ice} = 21440/.017245 = 1,243,258.$$

The gas volume from the ice sphere of 1 cm radius is:

$$4.19 \times 1243,258.9 = 5,209,254.8 \text{ cu cms.}$$

The 1 cm radius ice ball with a volume of 4.19 cu cm will fill a sphere of 107.5 cm radius when vaporized at 1.4 mm Hg.

With a radius more than 100 times as large, the bubble surface tension pressure is now only .013 mm Hg to contain saturated steam with a pressure of 1.4 mm Hg. This simply tells us that the expansion won't happen this way. Long before the ice ball has evaporated, the mercury bubble will have exceeded the one meter radius to contain the expanding gas.

But by assuming this path we have the volume of and pressure of saturated gas to be expanded as a superheated vapor using the perfect gas law, $PV = NRT$. The pressure inside the expanding space bubble will now drop at a rate inversely proportional to volume, which is proportional to the radius cubed. The rate of surface tension pressure drop of the mercury film, containing the expanding gas, is a much slower rate proportional to the inverse of the radius.

When the volume of the bubble is large enough for the pressure of the superheated steam at -13.7 C° to equal the surface tension pressure of the bubble, the bubble will stop growing. This happens when: (See Fig. 1)

The one centimeter radius ice ball will produce a 11.15 meter radius mercury bubble in space. This is well within the size range for stable mercury bubbles as indicated in the previous table. If chilled to -38 C,° the bubble would become a metallic vessel, that could contain gasses or liquids. It might also act as a mold. This mold, for example, could be sprayed with fiber glass and epoxy resin, then heated to reclaim the mercury for use in manufacturing another vessel.

Apply Methods

This method of expanding a surface tension liquid sphere by inserting a solid pellet, with a higher vapor pressure than the liquid, is not limited to ice and mercury. For any liquid, with a high enough surface tension and a low enough vapor pressure to exist in the vacuum of zero gravity space as a surface tension sphere, it should be possible to find a solid pellet with correct thermodynamic characteristics to expand it to the required size. The size of the solid pellet depends of the size of expansion required. Once the pellet size is determined, a pellet material can be chosen with a vapor pressure equal to the surface tension pressure of a bubble, made of the liquid to be expanded, that has the same diameter as the solid pellet. This pellet will produce an expansion similar to the ice in mercury example.

Fortunately, the elements of the periodic table that have the correct combination of low vapor pressure and high surface tension necessary to be stable surface tension spheres are the metals. The same metals whose strength is required to construct useful space vessels capable of containing liquid or gas and to shield human habitation from radiation.

Fig. 1.	
Gas Pressure	= Surface Tension Pressure
$p \text{ saturation}(V \text{ saturation}/V \text{ containment})$	= $1.4/r$
$1.4(5209254)/3/4\pi r^3$	= $1.4/r$
r	= $\sqrt{5209254/3/4\pi}$
r	= $1115. \text{ cm}$