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John's Corner Technical Blog

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Stable vs. Transient Cavitation

I have talked about cavitation extensively in previous blogs. But what I have neglected to address through an omission on my part is the fact that all cavitation does not produce the effect needed to enhance cleaning – namely, the catastrophic collapse of the cavitation bubble in implosion. Before reading further, please take a minute to check out this YouTube video which illustrates the power of ultrasonic implosion produced by the collapse of a cavitation bubble.

Pretty amazing isn't it! I must try that next time I go to a wild party with a bunch of my nerdy friends! But let's get on with the science.

As discussed in Cavitation 101, cavitation bubbles are formed in a liquid when the tensile strength of the liquid is exceeded due to some external force. The external force could be the wake of the trailing edge of a ship's propeller, a rapid movement as shown in the video or, in the case of ultrasonics, by the passing of the rarefaction of a sound wave. The cavitation bubble is really just a pocket of negative pressure trapped within a liquid. This results in the formation of an area (bubble) of low pressure.

Once formed, a cavitation bubble is a rarified cavity which initiates vaporization and outgassing of the surrounding liquid. The cavitation bubble has no means of support other than any contained vapor and gas once the event that created it has passed. It is destined to collapse one way or the other!

It is the mechanism of the collapse of a cavitation bubble that differentiates between "stable" and "transient" cavitation. The mechanism of collapse depends on the amount of energy introduced to produce the bubble and the ambient condition and nature of the liquid surrounding the bubble during collapse. More energy means a larger bubble which, in turn, means more energy stored in the bubble. The nature of the liquid determines how quickly vapor of the liquid and, potentially, other gas absorbed in the liquid will transform into vapor within the bubble as a result of low pressure and how quickly the vapor and gas will re-adsorb and re-absorb into the liquid once the bubble starts to collapse. This is determined by properties including surface tension, vapor pressure, the amount of dissolved gas and its diffusion rate and many others many of which are related to temperature (reference blog) which, by the way, is why temperature is such an important parameter in ultrasonic cleaning.

In the case of stable cavitation, one of two things happens. The contents of the bubble may not be fully re-dissolved into the surrounding liquid as it collapses leaving the bubble remnant as a "seed" for a bubble which oscillates and may grow in size with the passage of subsequent sound waves. The other option is that the now gas-filled remnant of the bubble is sufficiently buoyant to float to the surface of the liquid. This is what happens during degassing.

If, however, the cavitation bubble is large enough to contain enough energy and inertia to overcome the resistance of any vapor or gas it may contain, the result is called “transient cavitation.” This is the cavitation that is useful in ultrasonic cleaning. The violent collapse of the cavitation bubbles produce high pressure shock waves at the surface that is being cleaned. These shock waves displace particles and enhance the chemical effect of cleaning agents.

Relating back to the video, let’s imagine that the top of the bottle was not hit with sufficient force to create a large enough cavitation bubble at the bottom to collapse releasing sufficient force to break the bottle. In effect, this would be “stable cavitation.” Basically, the cavity is created but the contents migrate back into the liquid without any associated effect. Stable cavitation may also occur if the cavitation bubble is filled by vapor or gas that had been adsorbed in the liquid and was released by the differential pressure created within the cavitation bubble. The gas or vapor trapped within the bubble acts as a cushion to prevent implosion. As you could see in the video, in the case of carbonated liquid, the gas released from the carbonation prevented the violent collapse of the cavitation bubble in just this way. The effect of ‘transient cavitation,” was breakage of the bottom of the bottle due to the associated shock wave.

In the blog Ultrasonic Power vs. Cavitation Density, it is safe to assume that there is at least some stable cavitation at the bottom of the curve below what we call the “threshold of cavitation” is reached. Also, it is known that cavitation bubbles may oscillate (form and partially or fully collapse) many times before they reach sufficient size to collapse violently in implosion in an ultrasonic field. The “take away” here is that not all cavitation results in the violent and useful collapse we call implosion. The amount of energy and the nature of the liquid are significant factors which define the conditions for cavitation bubbles which implode producing the effects that enhance cleaning.

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