



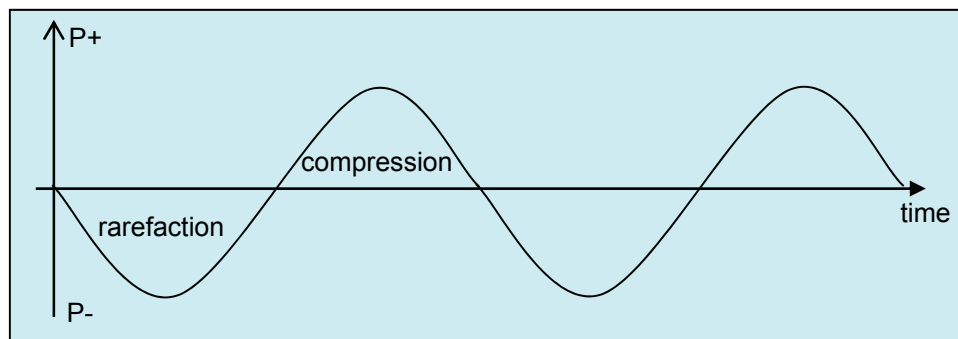
4D-3D
SOLUTIONS
PROVIDER

Ultrasound cleaning

May 2011

General points

- Naturally produced by a passing an electric current through quartz under constraint (piezoelectricity), ultrasound are waves produced by mechanical vibrations which, by definition, oscillate at frequencies above the ones heard by the human ear, 18 kHz.
- There is no above limit when it comes to frequencies, the megasonics are the continuity of ultrasounds at frequencies above 700 kHz.
- Discovered over a century ago, ultrasounds are today very useful in many areas : sonar, medical ultrasonography, industrial welding, chemical products synthesis and cleaning.
- Let us be reminded that sound is the propagation of an oscillating wave, alternatively going through a pressure phase (« $P > 0$ », compression) to a depression phase (« $P < 0$ », rarefaction) [Fuchs, 1995]. The ultrasound wave propagates according to this equation:
- $P = P_H + P_M \sin(2\pi ft)$
With P , the local pressure, P_H , the hydrostatic pressure in a environment with no wave, P_M , the maximum local pressure, f , the frequency (Hz) et t , time (s).

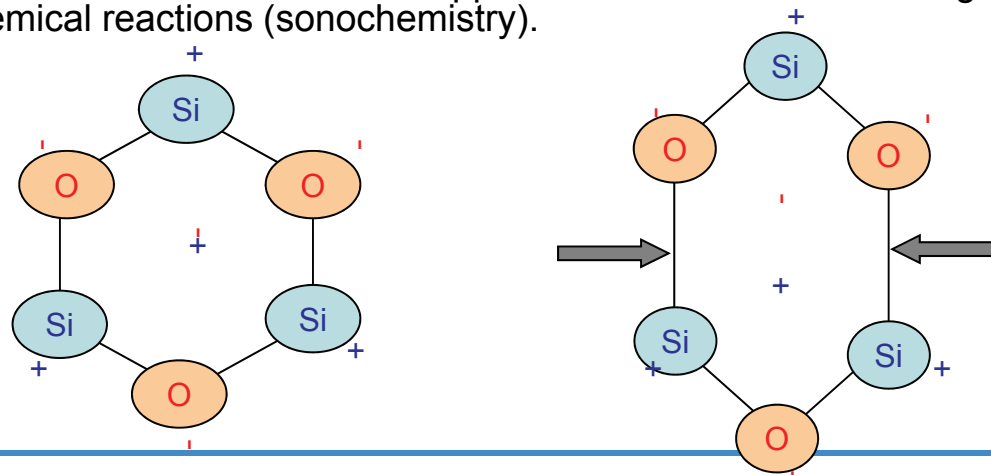


Producing ultrasound waves

- The machine generating ultrasound is called a transducer. By applying an electric field on a quartz blade, it contracts or expands itself depending on the direction of the field. Depending on the size and the orientation of the crystal cut, different frequencies can be obtained.

Low frequency ultrasounds don't propagate in air but only in liquids and a few solids. Glass and metals let ultrasound go through them while plastics are usually a barrier to the propagation of these waves.

- Two different types of ultrasound can be distinguished depending on their power range: the low and the high powers that will define their field of application:
 - The first ones (a few milliwatts to a few hundreds of milliwatts) are used for their capacity to propagate in environments. One impulse in the studied environment is emitted and, thanks to receptors, the echo(s) of this impulse are picked up: sonar, ultrasonography or distance measurement (telemetry) are the application fields.
 - High power ultrasounds (a few hundreds milliwatts to a few kilowatts) modify the environment in which they propagate, their principal actions are mechanical, thermic and/or chemical. This kind of sonic waves find their applications in industrial cleaning and the activation of some chemical reactions (sonochemistry).



Piezoelectricity principle: the crystal compression move the charges generating the electric field

Ultrasounds in water

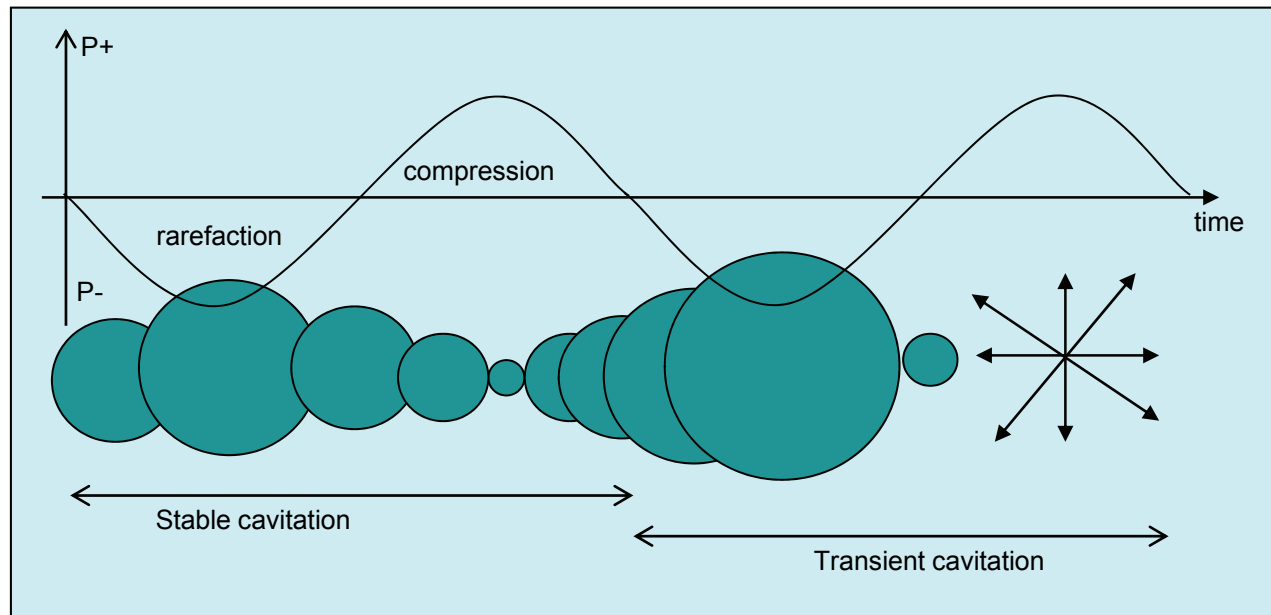
- Ultrasound cleaning is used to take away the particles ($>0.1 \mu\text{m}$) or matter aggregates. The first patent on ultrasound cleaning was in 1943.
- A lot of industries use this technique to clean out different kinds of parts, whatever their sizes or shapes. Ultrasounds are used to: clean off grease residue (pocket knife, metallic parts...) and grease marks (optical glass), disinfect surgery equipments... These cleaning operations are often done in surfactants and disinfectants. The volume of the ultrasound tank can vary from 0,5 L to 3 m³ to clean parts up to 1500kg.
- The advantages of ultrasound cleaning are: the possibility to get to all of the nooks and crannies of the part, the speed of execution, the use of low temperatures and the low quantity of chemical reagent.
- Furthermore, ultrasound cleaning, in spite of a high investment to buy the equipment and the potentially high electric consumption, is still a cheap technique, the maintenance of the equipment being low and the running cost being under the cost of using pure chemical products.



Ultrasound
cleaning tank

Ultrasounds in water

- One of the characteristics of the high powers is their capacity to generate bubbles of cavitation. The acoustic cavitation phenomenon provokes the creation, the increase and then the implosion of bubbles created when a liquid is under a wave of periodic pressure (see drawing here under).

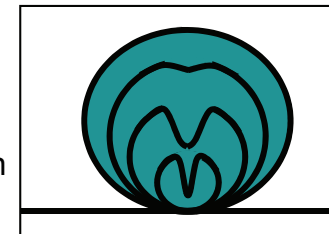


- Two types of cavitation exist. Stable cavitation means that the bubble has a stable medium radius and its life expectancy is above an ultrasound wave cycle. Transient cavitation implies big bubbles and a violent implosion [Gale, 1999].

Cavitation bubbles

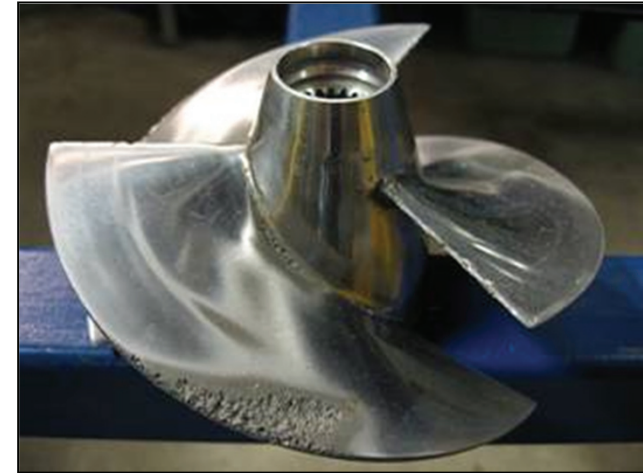
- A bubble is created from a nucleus in the depression stage ($P < 0$). It can be a bubble or a particle in the environment or, more often, the nuclei are the solid-liquid interfaces, meaning they are the immersed solid surfaces.
- The size of the bubbles depends on the frequency used, as we will see later on in this paragraph. One usually says that the lower the frequency is, the bigger the bubbles are, 150 μm at 20 kHz.
- The cavitation bubbles oscillate with the waves and, once the pressure is too low outside of the bubble, the bubble collapses and implodes. This last phenomenon lets out a very powerful energy represented by temperature scales from 5000 to 10000°C and pressure scales from 150 to 10000 atm, depending on the author [Suslick, 1988], [Gonze, 1998], [Awad, 1996], [Franc, 1995].
- The bigger the bubble is, the more energy is generated when it collapses.
- The effect of cavitation is violent since the implosion lasts about 1 μs , that the pressure is very localized (a few μm^2) and that the implosion speed is about 100 $\text{m}\cdot\text{s}^{-1}$ [Franc, 1995].
- During the implosion phase, the outermost side of the bubble is pushed inwards and forms a concave cone which strikes the surface on which the bubble formed [Franc, 1995, p113], [Boujouk, 1988].

Steps of the collapsing of a cavitation bubble on a surface [Franc, 1995]

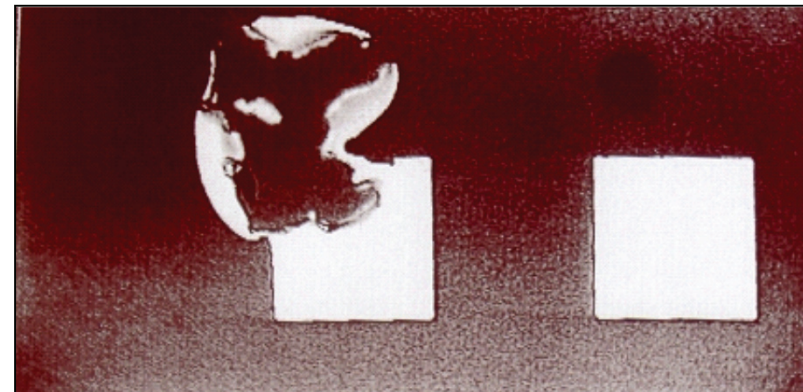


Bad effects of cavitation

- Cavitation is an involuntary phenomenon known by the mechanics in the field of the hydraulic turbo machines and nautical propellers. Indeed, cavitation damages the propellers of ships (picture on the top-right).
- If the settings aren't right, ultrasound cleaning can damaged irremediably the surfaces (picture on the bottom-right)
- Therefore, it is very important to set the parameter properly:
 - Frequency
 - Power
 - Temperature



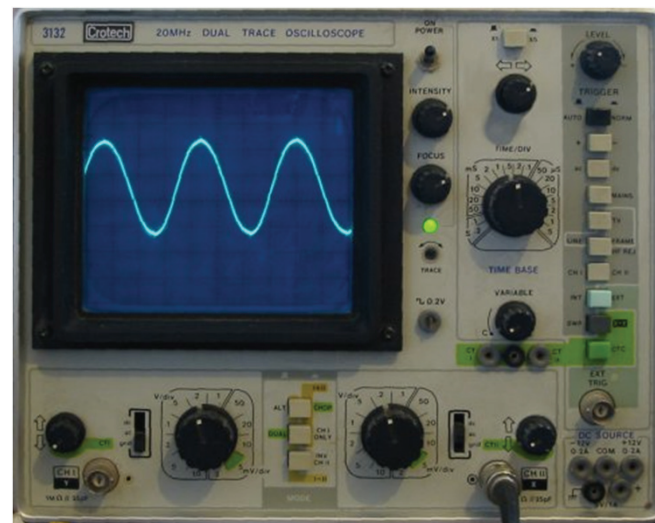
Boat propeller damaged by cavitation
(Wikipedia)



Effect of cavitation in water at 80 kHz for 30 min on a molybdenum deposit (square of 400 μm by a few μm thick) on a glass substratum

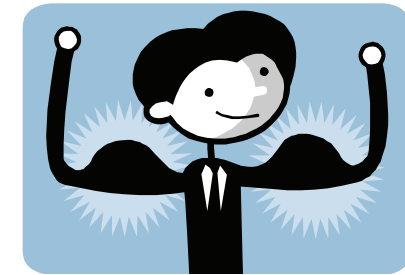
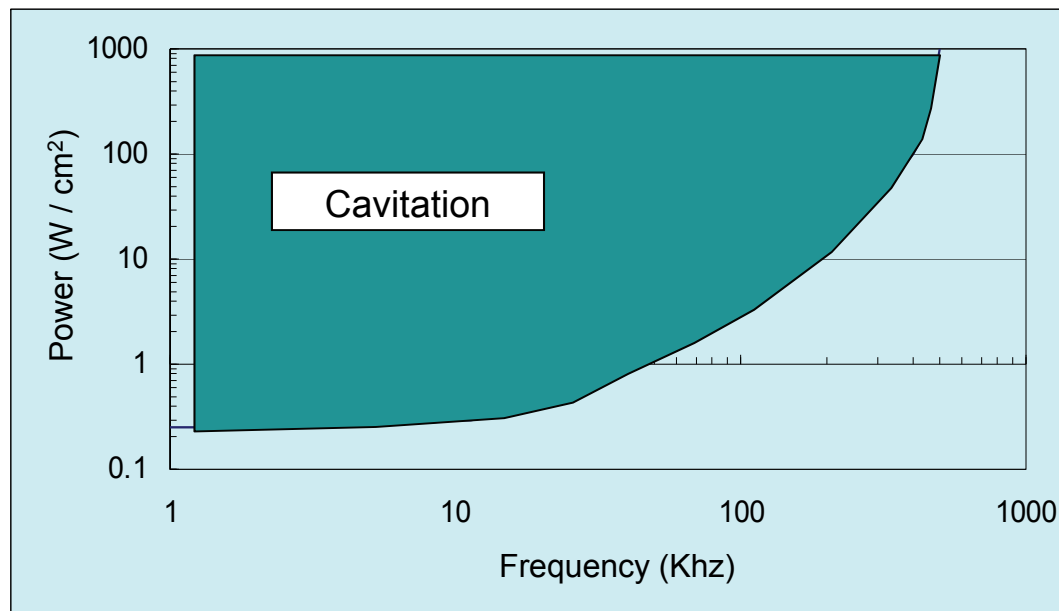
Effect of the frequency

- The choice of the ultrasonic frequency depends on the contaminants that need to be cleaned off. Even though no particular correspondence is given in literature, one tendency is often admitted:
 - Low frequencies generate a little amount of bubbles but with big diameters so it frees out a lot of energy
 - Frequencies between 25 and 40 kHz are generally used to remove particles between 25 and 200 μm [Awad, 1996].
 - The higher the frequency is, the smallest the bubbles are and the more it cleans off the small particles.
 - It has been observed that, at 40 kHz, particles of 2 μm can be cleaned off and that, at 1 MHz, their diameter is about 0.15 μm [Lamm, 2001].



Effect of the power

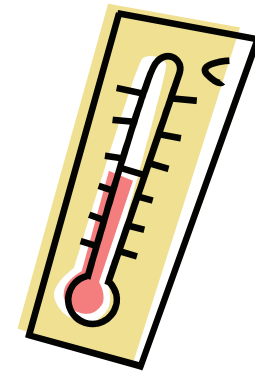
- At a given frequency, the power defines the cavitation threshold, above a certain power, cavitation happens, underneath, there is only the spreading of the waves in a environment as shown on the empirical schematic underneath.
- Therefore, underneath this cavitation threshold, we are in an area where ultrasounds only create wave movements within a environment.



Cavitation area, depending on the power and frequency [Mansard, 2000].

Effect of the temperature

- Temperature plays an important part in cavitation. The increase of temperature increases the saturated vapor pressure of water, which eases the creation of bubbles.
- Furthermore, an increase of temperature produces a decline of the viscosity of the liquid, which helps the movements in the fluid and magnifies the cavitation. This point is relevant up to a certain temperature. Indeed, above this temperature, the cavitation bubbles entering in collision with the vapor bubbles loose their implosion capacity.
- Therefore, the literature sources do not concordate on the ideal working temperatures. Some say 40°C for an efficient cleaning cavitation in water [Visser, 1995], and some other say 70°C is this ideal temperature [Suslick, 1995].



Effect of other parameters

- In order to obtain a good cavitation quality, it is necessary to work with an average quantity of gas dissolved in the liquid. Indeed, when the bubbles get bigger (when going from depression to pressure), the dissolved gases get inside the bubble, the pressures get even and there is no implosion. Nevertheless, the presence of dissolved gases is useful to help the nucleation of the cavitation bubbles [Aymonier, 2001].
Let's be reminded that the cavitation nuclei are formed by the inclusions of gases and vapors present in the environment [Franc, 1995].
- Other parameters have an influence, they have not been studied in literature. The hydrostatic pressure, the quantity of particles contamination and the ion concentration are stated in the Atchley *et al.* article [Atchley, 1988].



Case study

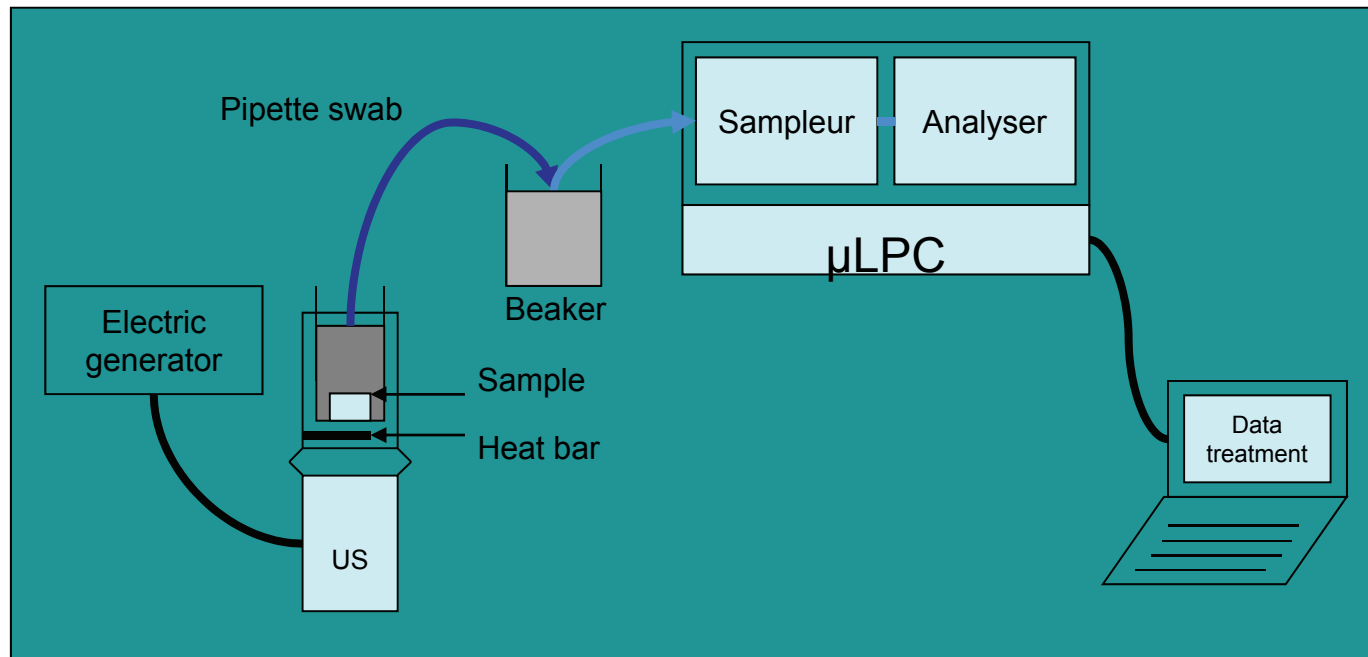
Case study: the part

- **Research of the optimum parameters to remove the particles on a alumina part**
- Information on the part: part ($\varnothing = 25$ cm) made of 99.8 % pure sinter fused alumina, no porosity, roughness RMS = $0.4\mu\text{m}$



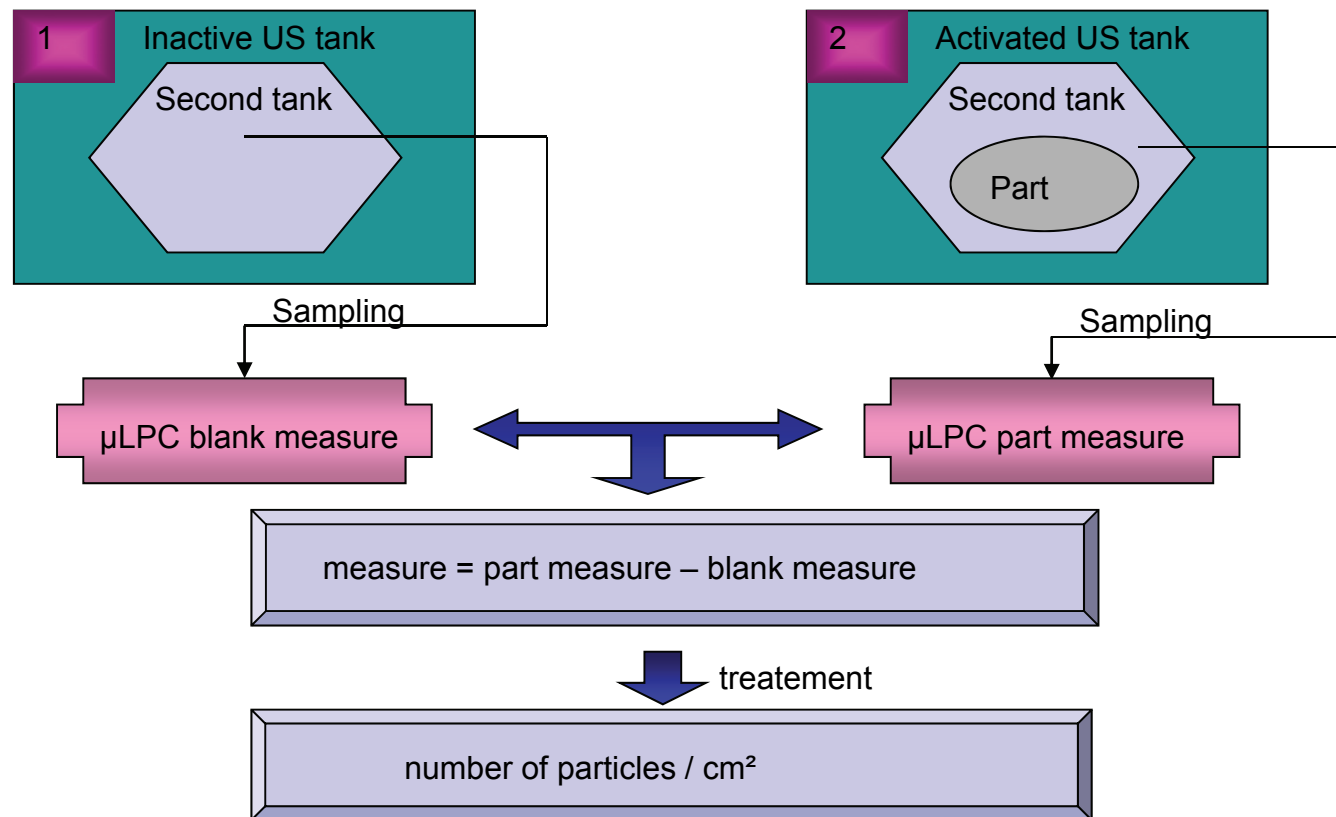
Case study: the tools

- Study of the particles removal by ultrasounds with research of the optimum parameters to remove them with no damage.
- Devices used: ultrasound generators (US) of various frequencies and particles counter in liquids (μ LPC).



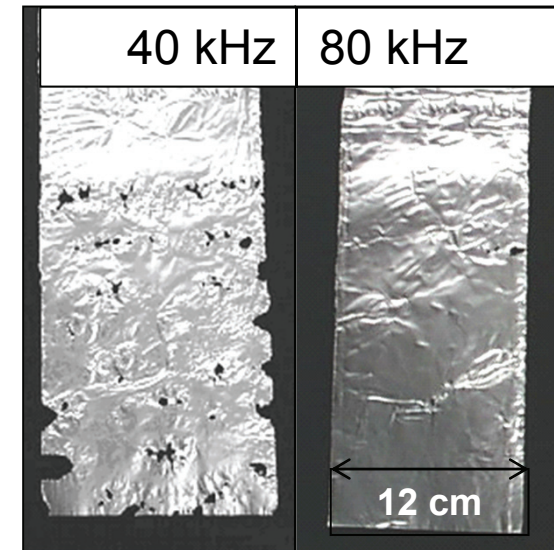
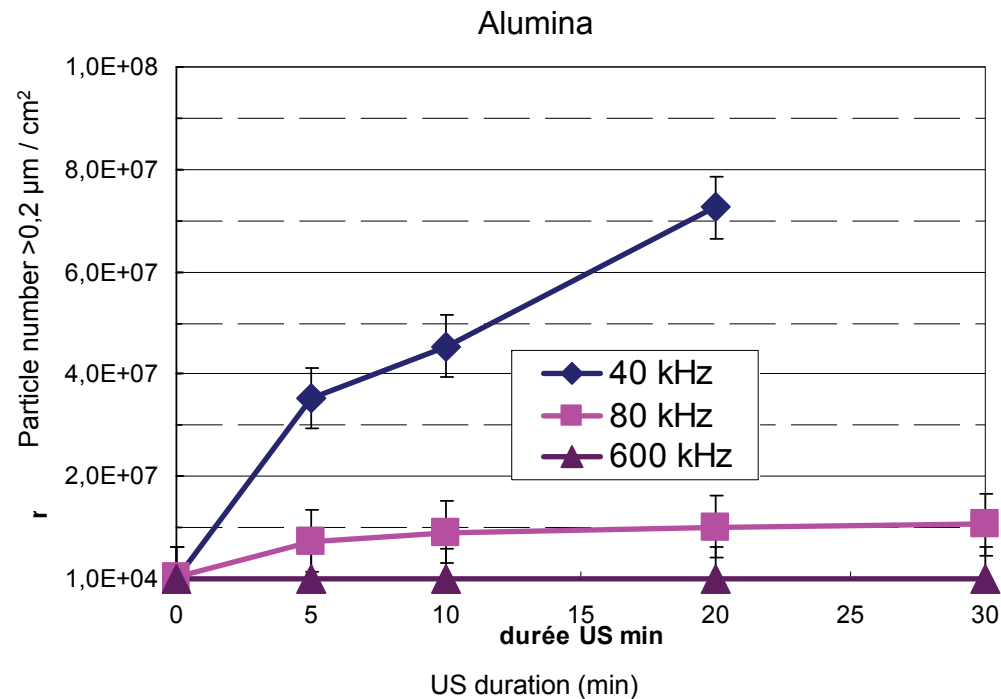
Case study: Measure principle

- Part are immersed in a water solution and particle removal with ultrasounds
- Particles in solution sucked and measured by a laser particle counter (μ LPC)



Case study: Choice of frequency

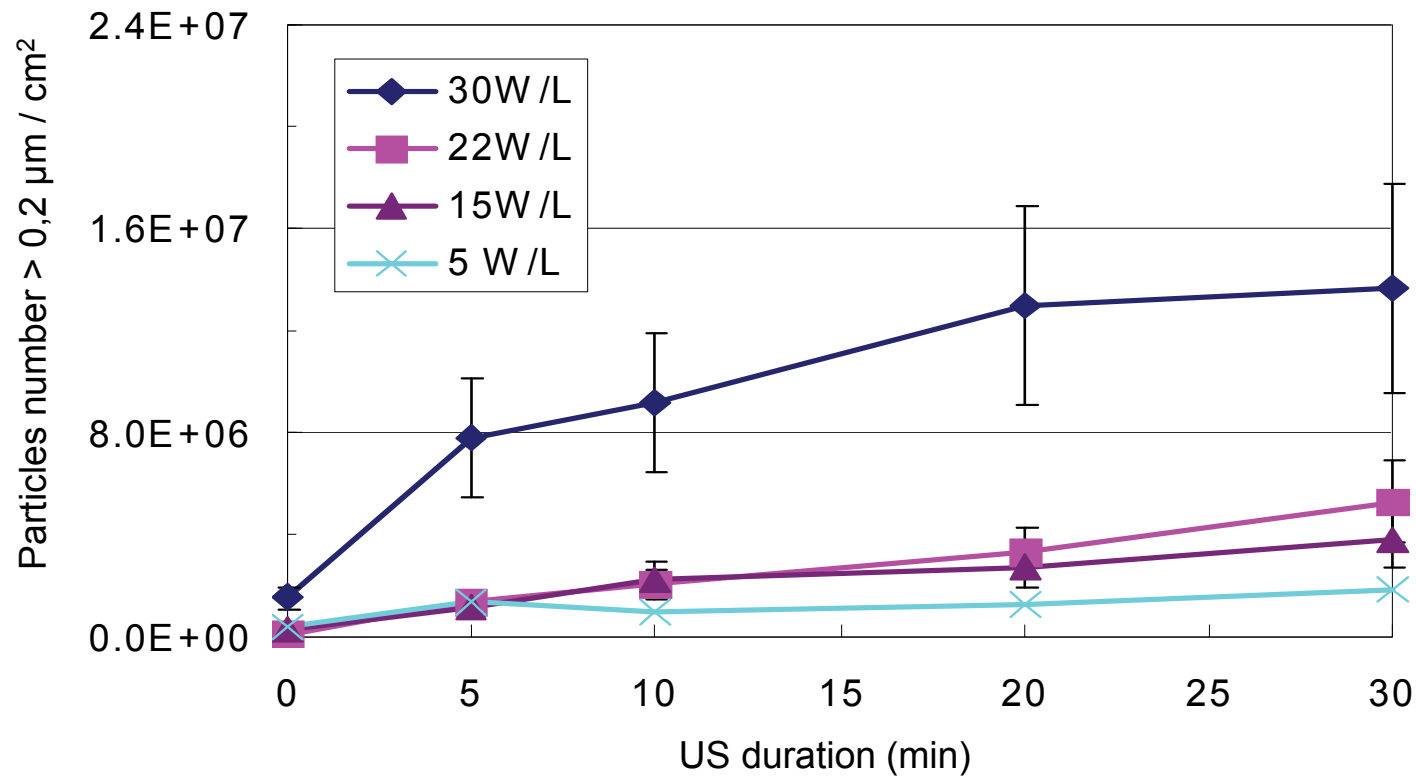
- 40 kHz = constant particles removal → damage done to the material
- 80 kHz = particles removal up to 10 min and stages → no damage done to the material
- 600 kHz = no particle removal



Effect of frequencies on aluminium foil, result obtained after 10 min in a ultrasound tank

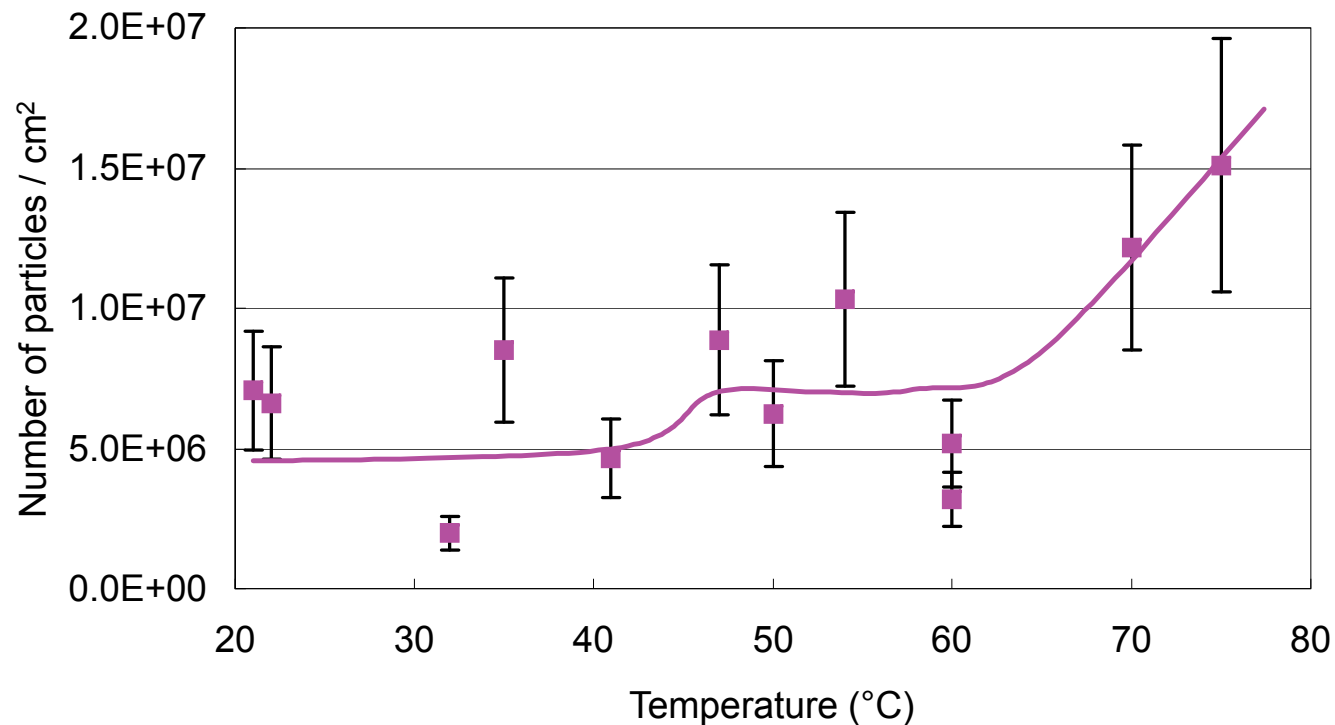
Case study: Choice of power

- From 5 to 22 W/L → constant particle removal
- 30 W/L → in 20 min, optimum particle removal



Case study: Choice of temperature

- 50 % improvement for particle removal between 45°C and 55°C → Ultrasound optimum temperature for efficiency
- Points at 70 and 80°C are water vapor bubbles seen by the counter as particles



- Ultrasound cleaning is very efficient for particle removal (particles > 0,1 μm)
- Ultrasounds aren't very efficient on plastic materials (no wave propagation)
- At temperatures below 55°C, ultrasounds are more efficient
- Ultrasounds are most efficient with fresh water that just came out of the tap
- For every material, it is necessary to find the optimum parameters: frequency, power and temperature for the best particles removal (compromise between non-removal of particles and damages on the parts)

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