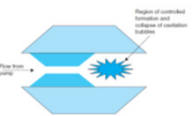
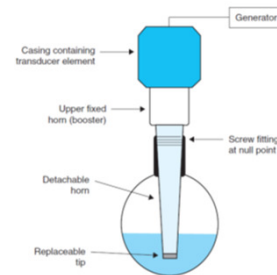
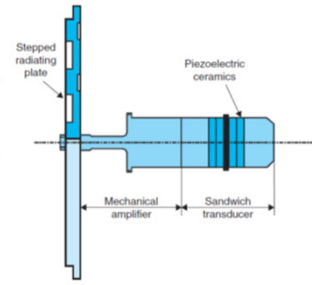


PROCESSAMENTO POR ULTRASSOM

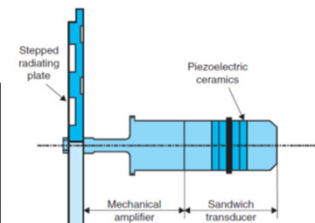
PROFA. DRA. CYNTHIA DITCHFIELD

Processamento por Ultrassom

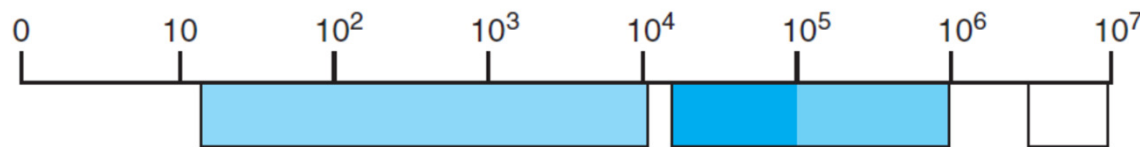
- Conceitos
- Equipamentos
- Aplicações







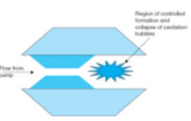
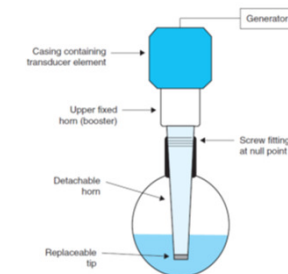
Processamento por Ultrassom



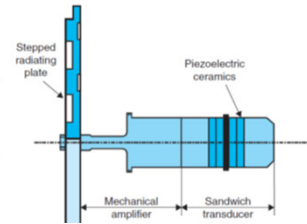
- Ondas sonoras com frequências maiores que o limite da audição humana
- Frequências utilizadas em equipamentos de 20 kHz até 10 MHz



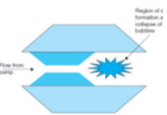
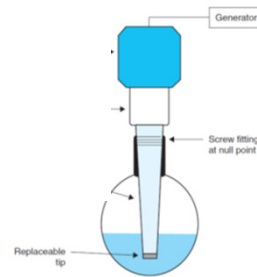
Human hearing		16 Hz–18 kHz
Conventional power ultrasound		20 kHz–100 kHz
Extended for special applications		20 kHz–1 MHz
Diagnostic ultrasound		5 MHz–10 MHz



Processamento por Ultrassom



- Onda mecânica longitudinal que se propaga através de um meio físico
- Parâmetros: velocidade (c), comprimento de onda (λ), frequência (f), amplitude (A) e intensidade (I)
- A velocidade depende do meio de propagação $c = \lambda f$
- Amplitude é a altura da onda



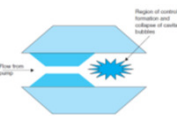
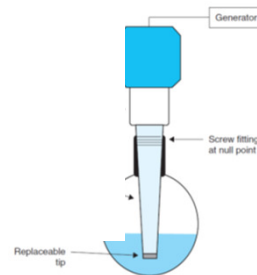
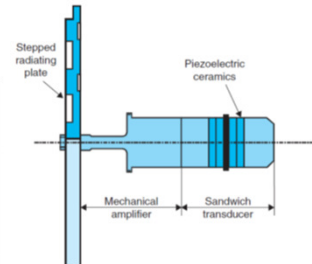
Processamento por Ultrassom

- Intensidade é o fluxo de energia acústica através de uma unidade de área por unidade de tempo $I = \frac{P}{A}$ (W/m²)

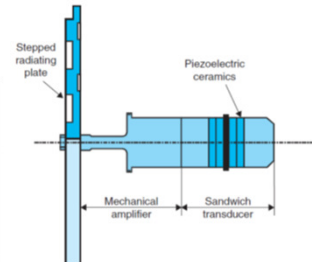
✓ Em que P é a potência do ultrassom que pode ser obtida por $P =$

$$mC_p \left(\frac{dT}{dt} \right)_{t=0} \text{ e } A \text{ é a área}$$

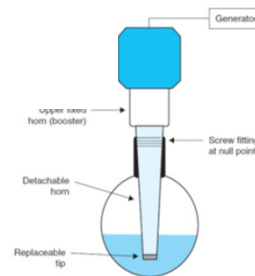
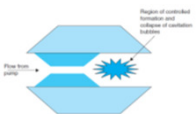
- Densidade de energia acústica (D) $D = \frac{P}{V}$ (W/m³)



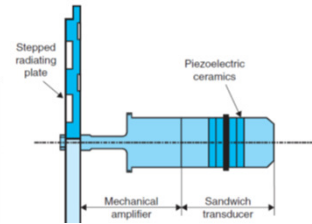
Processamento por Ultrassom



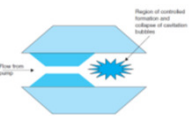
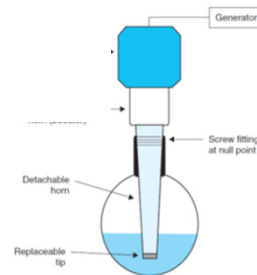
- Principal mecanismo de atuação do ultrassom é pela **cavitação**
- <https://www.youtube.com/watch?v=oRYYP4F8LTU>
- A propagação da onda no meio provoca compressão (pressão positiva) e rarefação (pressão negativa)



Processamento por Ultrassom



- Na rarefação se for excedida a energia de atração das moléculas da fase líquida forma-se uma bolha
- Baixas intensidades de ultrassom ocorre a cavitação estável formam-se bolhas que duram muitos ciclos
- Altas intensidades de ultrassom ocorre a cavitação transitória a bolha cresce e arrebenta



Processamento por Ultrassom

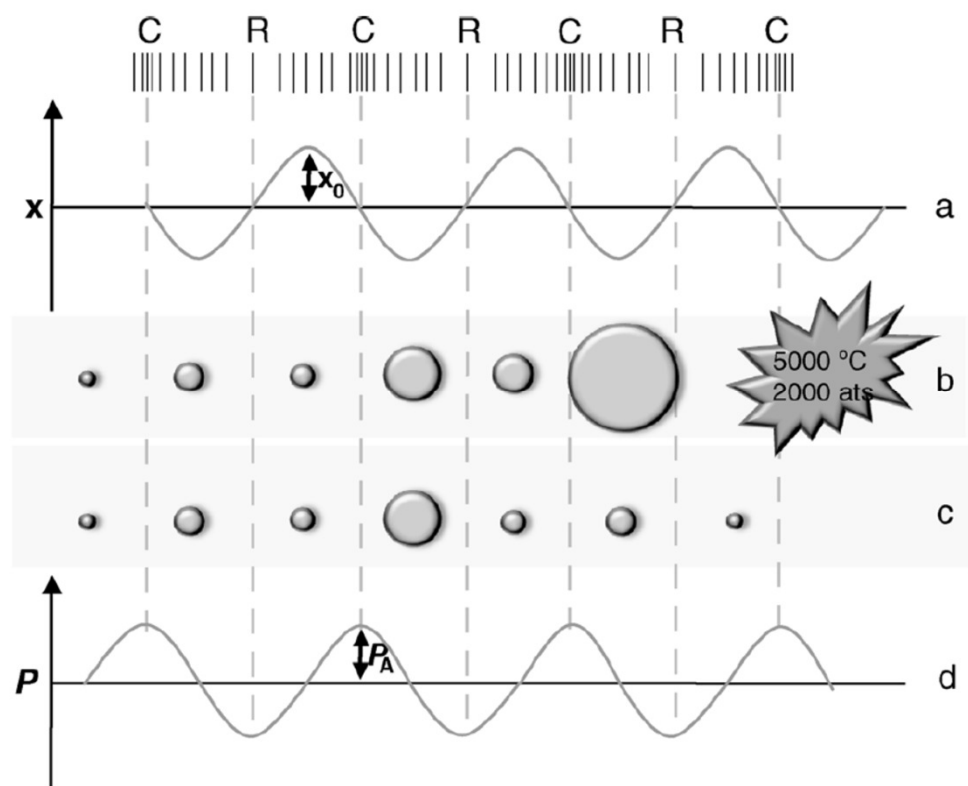
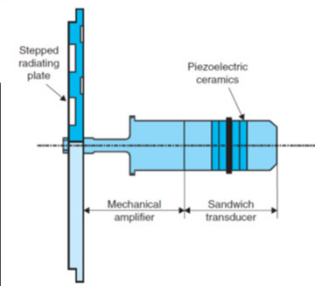
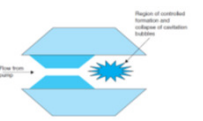
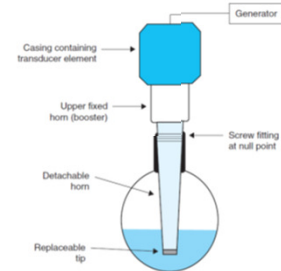
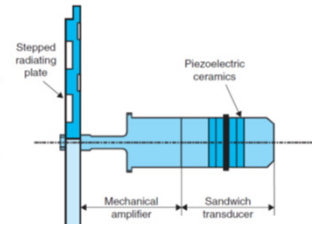


Figure 1.2 Creation of stable cavitation bubbles and creation and collapse of transient and stable cavitation bubbles.
 (a) Displacement (x) graph; (b) transient cavitation;
 (c) stable cavitation; (d) pressure (P) graph.

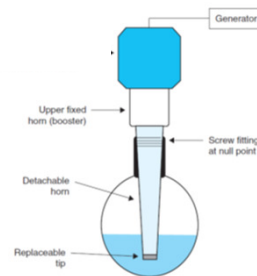
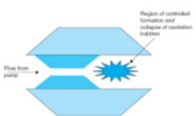
5000 °C
2000 ats



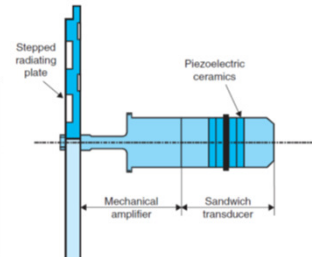
Processamento por Ultrassom



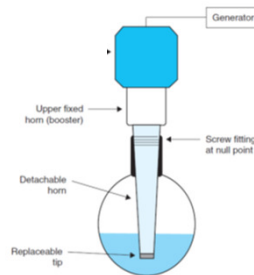
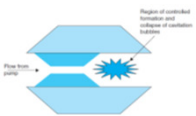
- O rompimento da bolha provoca a formação de uma corrente de fluxo, com alta tensão de cisalhamento, aumento de temperatura local e pressão, formação de onda de choque e próximo a superfícies sólidas jatos impingentes em alta velocidade



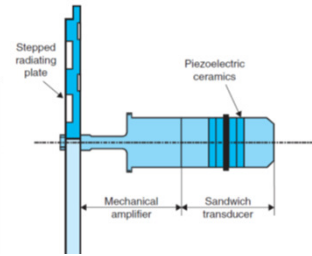
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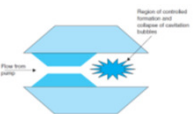
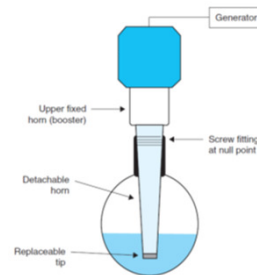
- A cavitação é determinada pela frequência da vibração, intensidade da vibração, viscosidade do meio, tensão superficial, pressão de vapor, atenuação da vibração pelo meio, presença de bolhas de gás, temperatura e pressão



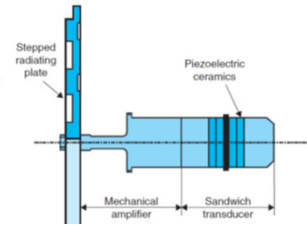
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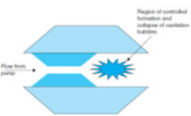
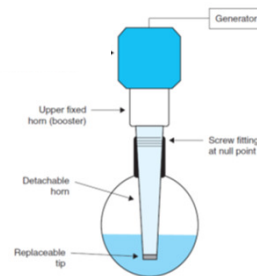
- Aumento da frequência dificulta a ocorrência da cavitação (comprimentos de onda menores, ciclos mais curtos)
- Existe uma intensidade mínima requerida para induzir a cavitação



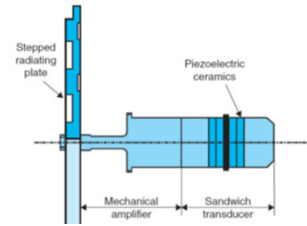
Processamento por Ultrassom



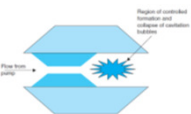
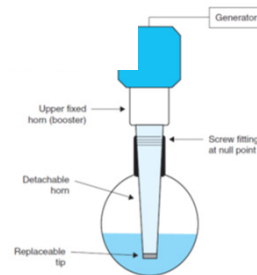
- A intensidade é proporcional à amplitude e seu aumento favorece a cavitação, porém altas amplitudes deterioram rapidamente o gerador de ultrassom
- Alta viscosidade e alta tensão superficial do meio dificultam a cavitação



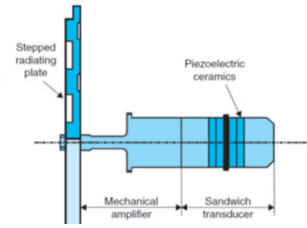
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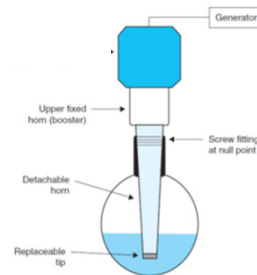
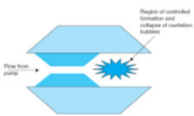
- Aumento da temperatura favorece a formação da bolha porém aumenta a pressão de vapor e o colapso da bolha é menos intenso
- Aumento da pressão externa requer uma energia maior para induzir a cavitação porém o colapso da bolha é mais intenso



Processamento por Ultrassom



- Bolhas de gás dissolvidas atuam como núcleos para cavitação entretanto pela diferença de densidade o gás é movimentado para a superfície e retirado do líquido



Processamento por Ultrassom

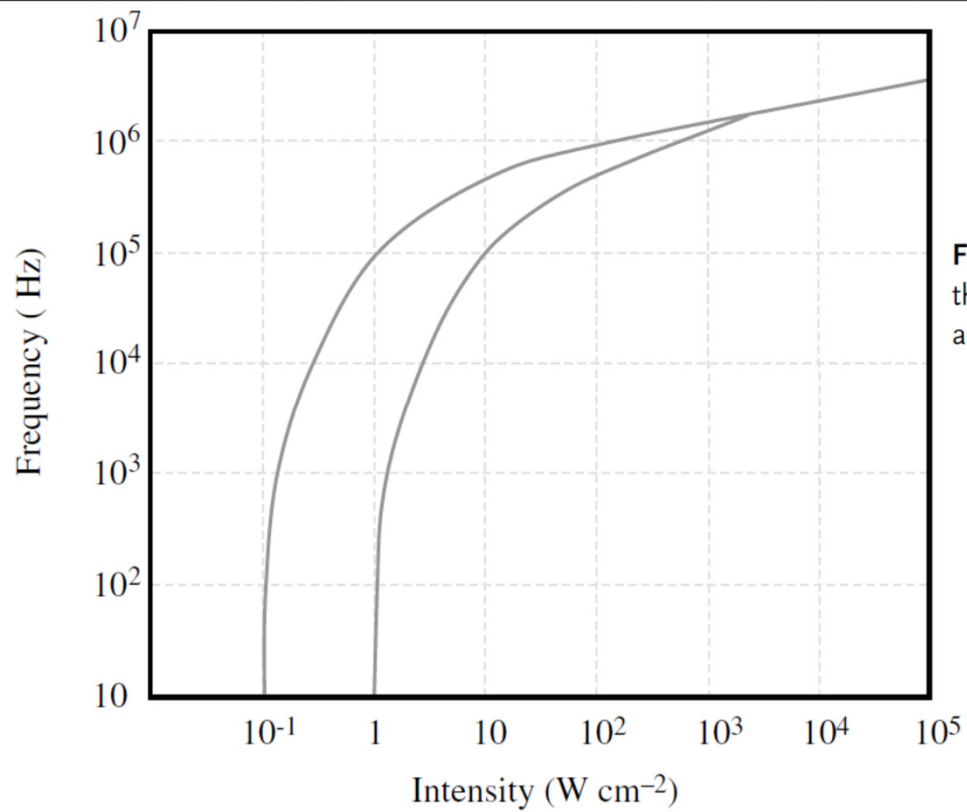
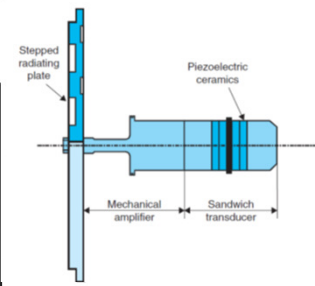
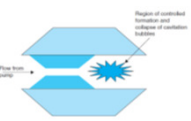
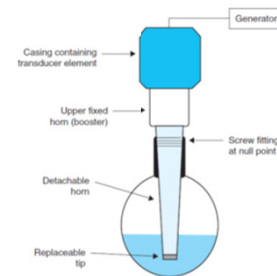
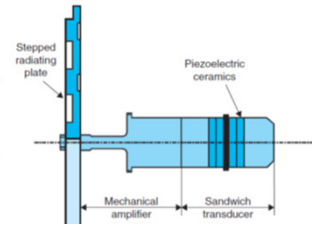


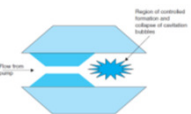
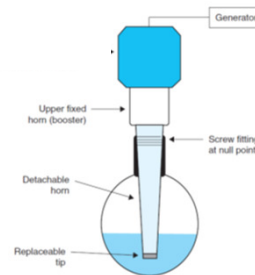
Figure 1.3 Variation of intensity of sonication versus the threshold frequency for aerated water (left-hand graph) and air-free water. Adapted from Ref. [1].



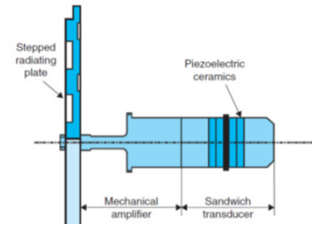
Processamento por Ultrassom



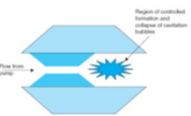
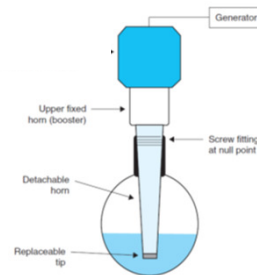
- A cavitação rompe células microbianas causando a sua inativação
- Fatores que afetam a inativação: tamanho da célula, formato, gram-negativos ou positivos, anaeróbios ou aeróbios, idade das células, células vegetativas ou esporos
- Difícil comparar dados pois as condições de ensaios variam muito



Processamento por Ultrassom



- Estabelece-se um tempo de redução decimal
- Inativação enzimática também ocorre por ultrassom
- Combinação do ultrassom com alta pressão (manosonicação), com temperatura (termosonicação) e com alta pressão e temperatura simultaneamente (manotermosonicação)



Processamento por Ultrassom

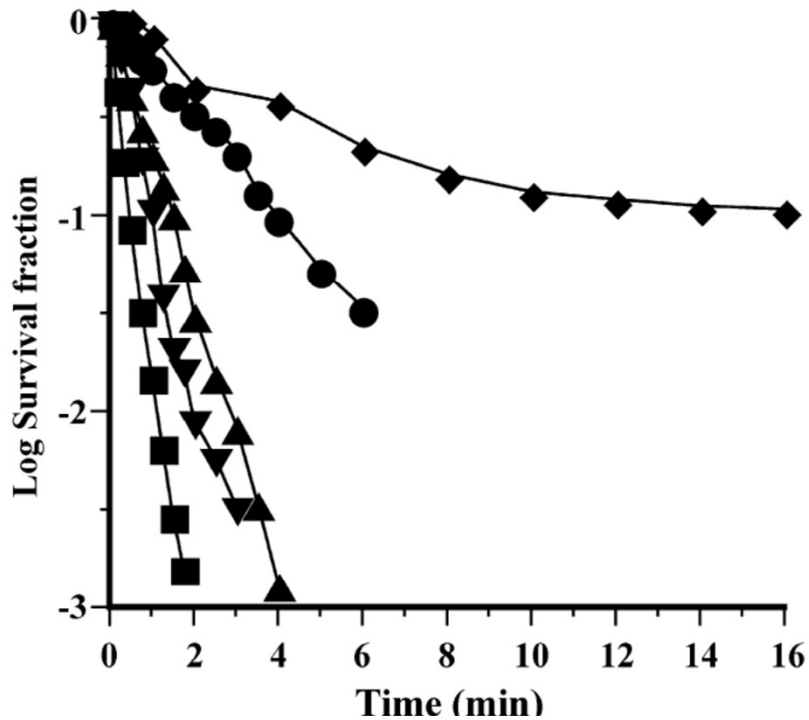
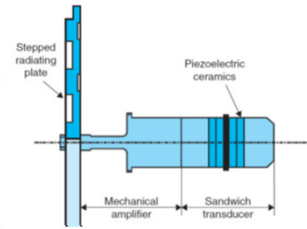
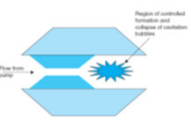
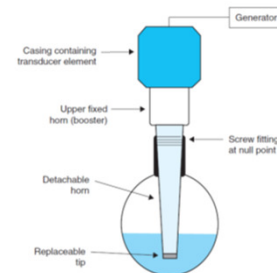


Table 1 Decimal Reduction Time Values for Heat (62°C) and Ultrasonic Under-Pressure Treatments (40°C, 200 kPa, 117 μm) of Different Bacterial Species

Bacterial species	Heat resistance	Ultrasonic resistance
<i>B. subtilis</i>	Insensitive	12.0
<i>L. monocytogenes</i>	0.62	1.5
<i>E. faecium</i>	15.3	4.0
<i>Y. enterocolitica</i>	0.39	1.2
<i>Pseudomonas aeruginosa</i>	0.18	0.92
<i>E. coli</i>	0.012	0.87
<i>S. enteritidis</i>	0.068	0.73
<i>S. typhimurium</i>	0.12	0.80
<i>S. senftenberg</i>	1.1	0.84
<i>A. hydrophila</i>	0.024	0.86

Figure 2 Survival curves for ultrasonic under-pressure treatments (40°C, 200 kPa, 117 μm) of *B. subtilis* (◆), *E. faecium* (●), *L. monocytogenes* (▲), *S. enteritidis* (▼), and *A. hydrophila* (■).

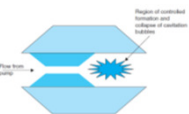
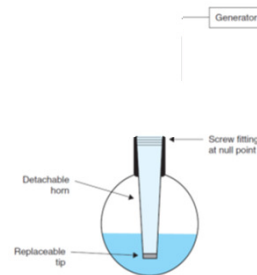
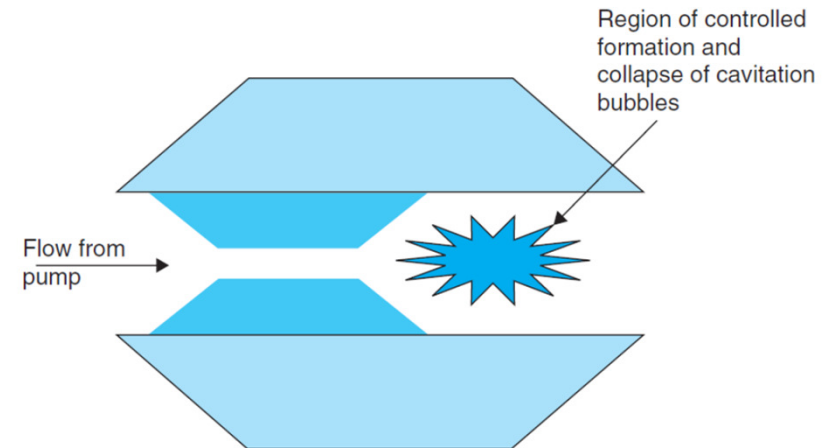
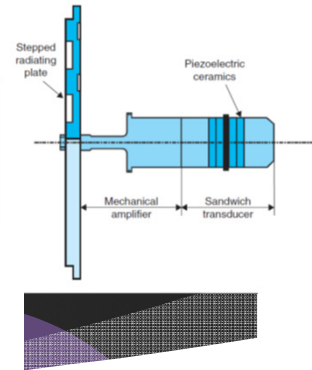


Processamento por Ultrassom

➤ Equipamentos de processo

- ✓ Geração de ultrassom: transdutores (mecânicos ou eletroacústicos)

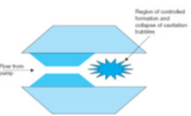
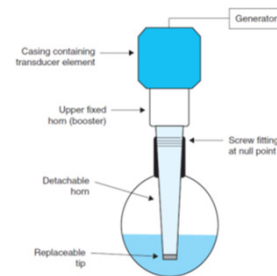
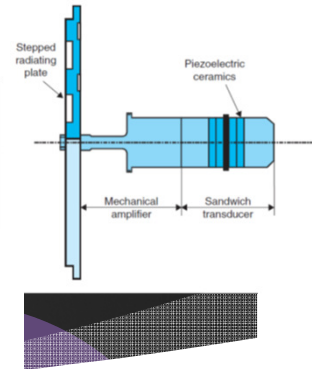
- Mecânicos: apito líquido ou gasoso



Processamento por Ultrassom

➤ Equipamentos de processo

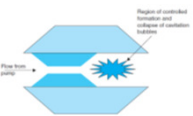
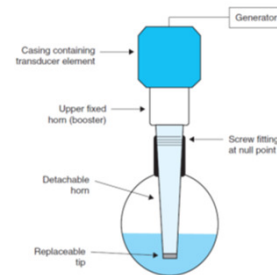
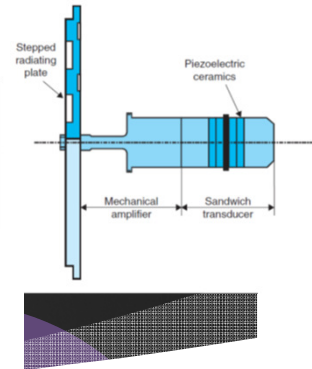
- ✓ Geração de ultrassom: transdutores (mecânicos ou eletroacústicos)
 - Magnetoestrictivos: alteração da dimensão de um material ferromagnético pela aplicação de campo magnético intermitente



Processamento por Ultrassom

➤ Equipamentos de processo

- ✓ Geração de ultrassom: transdutores (mecânicos ou eletroacústicos)
 - Piezoelétricos: material cerâmico com moléculas polarizadas que altera suas dimensões pela aplicação de um campo elétrico intermitente



Processamento por Ultrassom

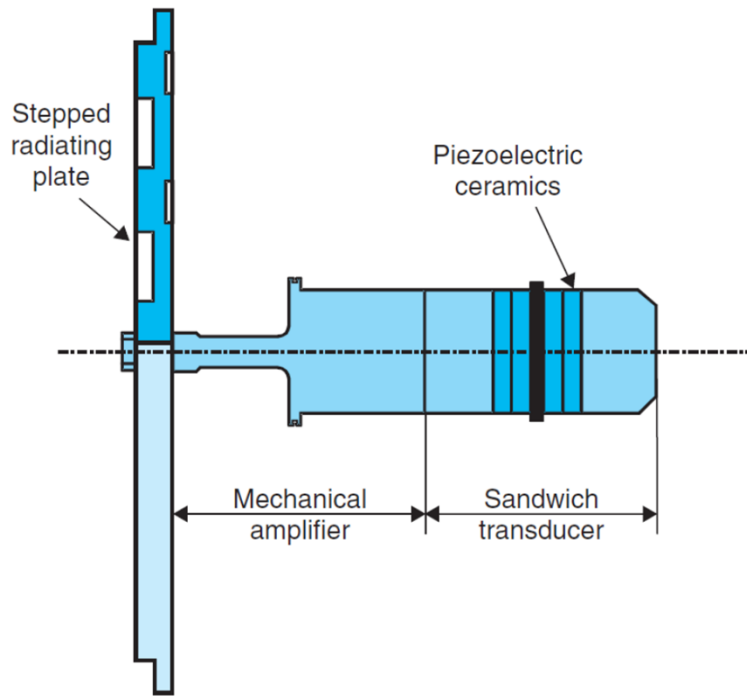
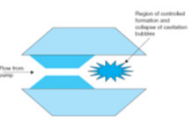
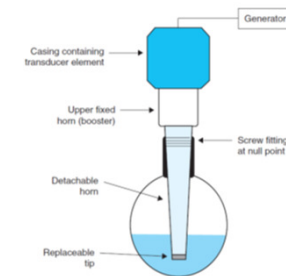
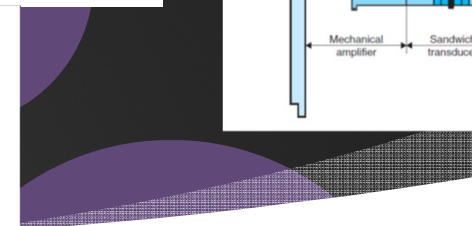
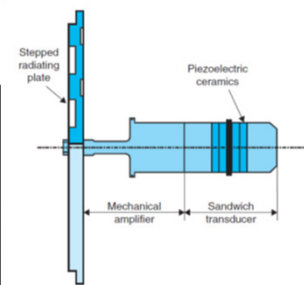
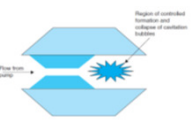
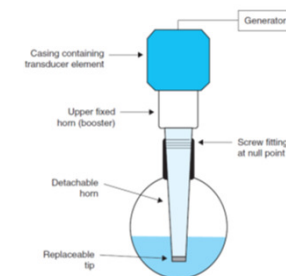
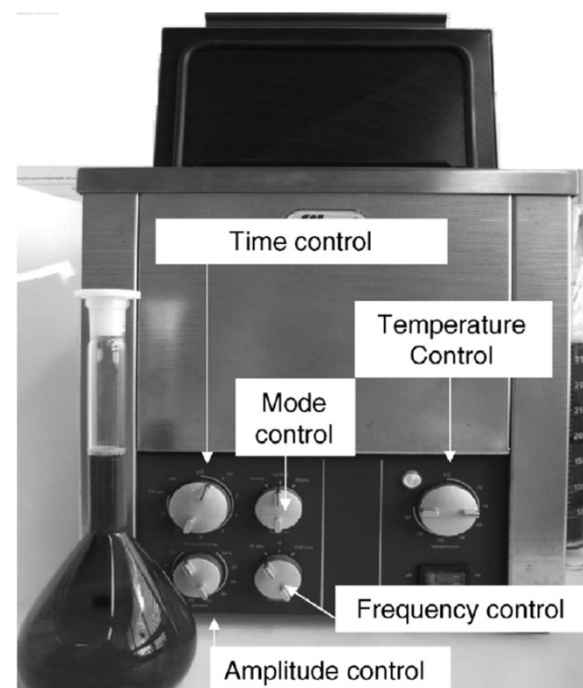
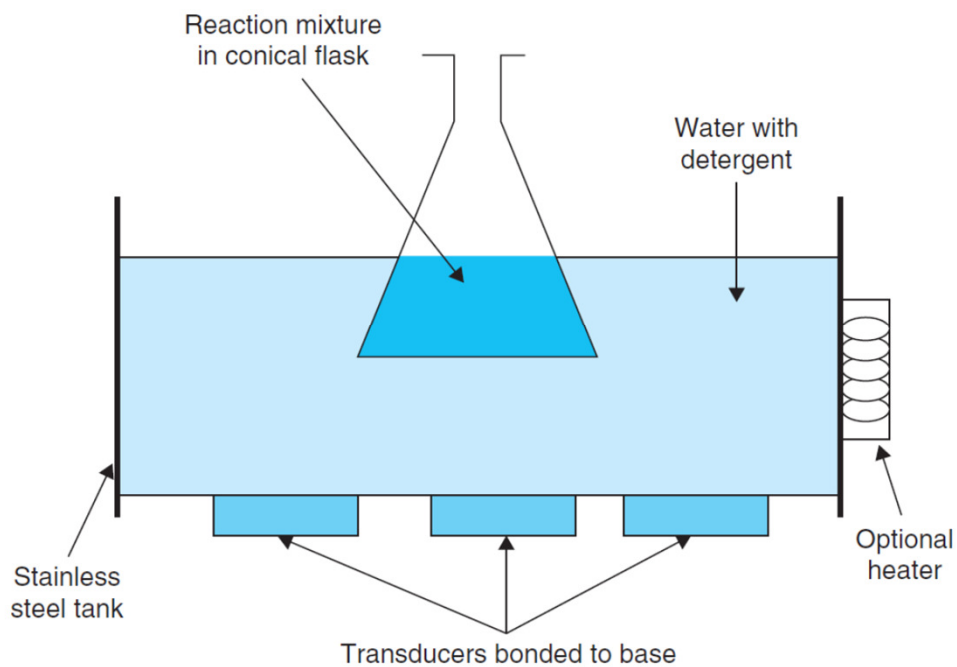
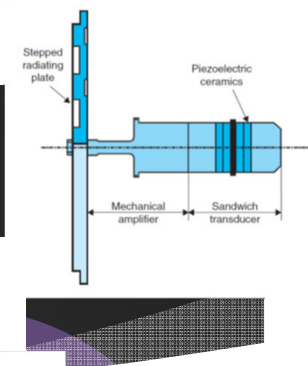


Figure 13.2 Dish emitter for airborne ultrasound.

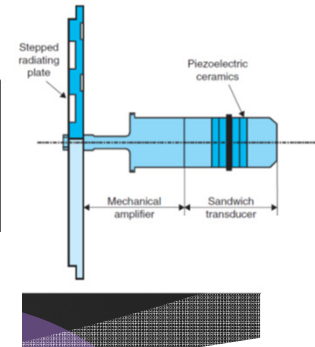


Processamento por Ultrassom

➤ Escala laboratorial: banho ultrassônico



Processamento por Ultrassom



➤ Pequena e Larga escala: sondas (*probes*)

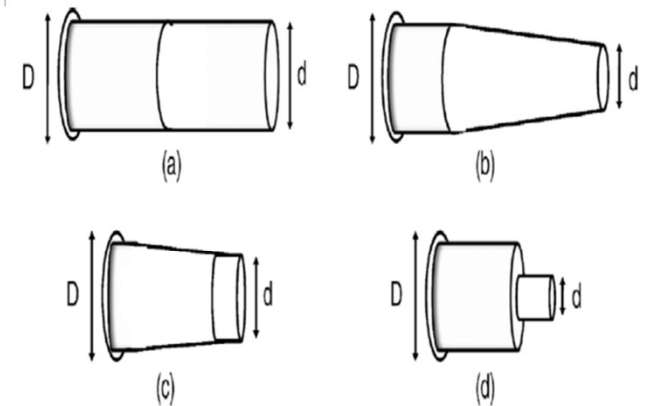
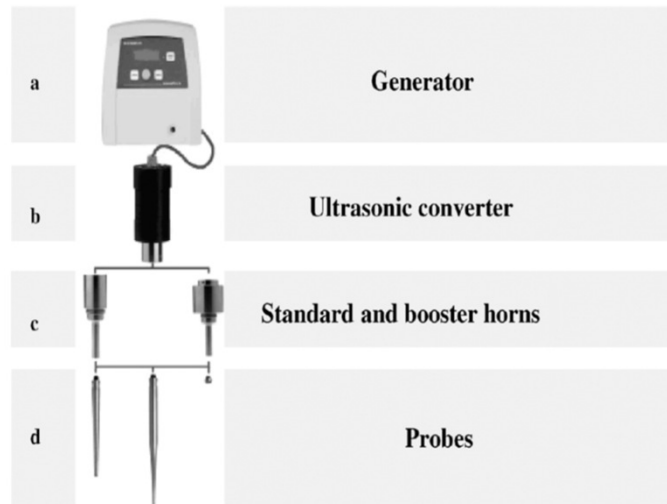
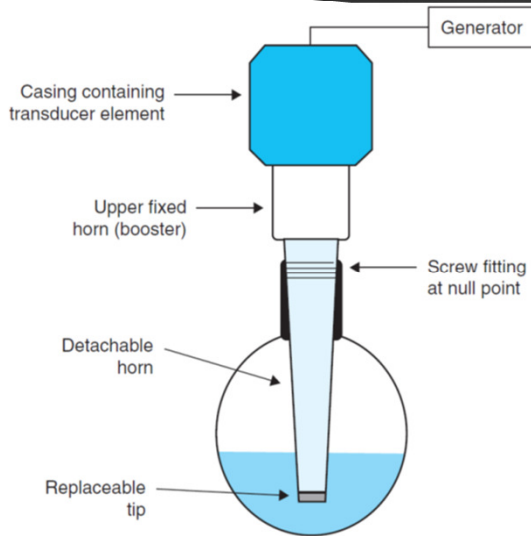
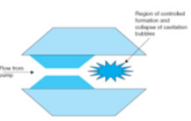
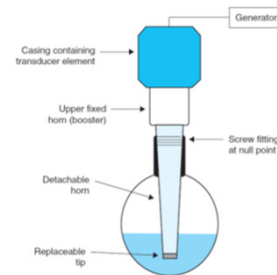


Figure 1.7 Probe shapes: (a) uniform cylinder; (b) exponential taper; (c) linear taper or cone; (d) stepped.



Processamento por Ultrassom

- Larga escala: sondas (*probes*) e reatores tubulares ressonantes

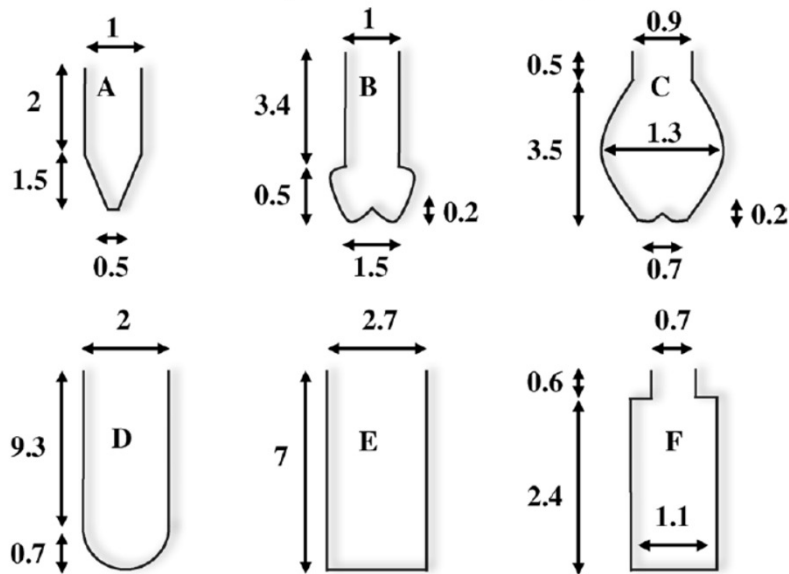
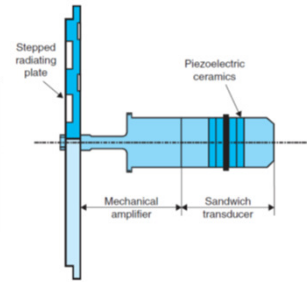


Figure 1.8 The shape of the vessel influences ultrasonic performance. The best forms are those that minimize “dead zones,” namely, forms A–C. Adapted from Ref. [13].

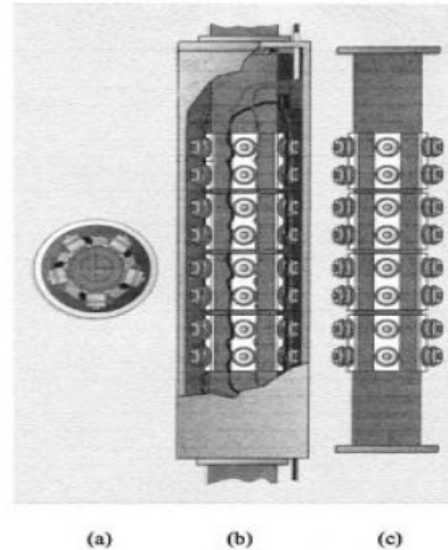
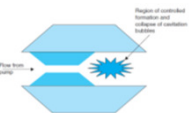
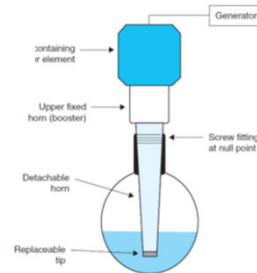


Figure 17. Cylindrical tube processor showing, from the left: (a) arrangement of transducers around outside of processing tube, (b) processing tube with outer protective casing, (c) inner processing tube with transducers attached.



Processamento por Ultrassom

➤ Aplicações

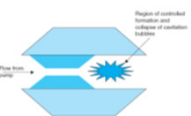
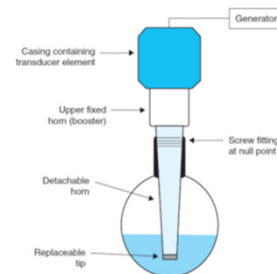
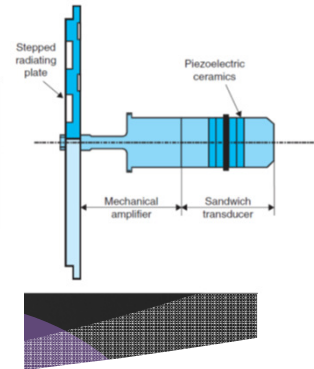
Table 13.1 Some uses of power ultrasound in food processing

Mechanical effects

- crystallization of fats, sugars etc
- degassing
- destruction of foams
- extraction of flavourings
- filtration and drying
- freezing
- mixing and homogenization
- precipitation of airborne powders
- tenderization of meat

Chemical and biochemical effects

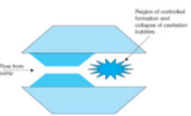
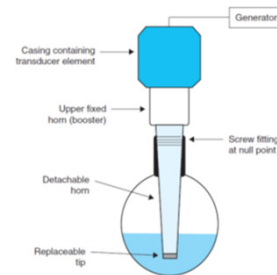
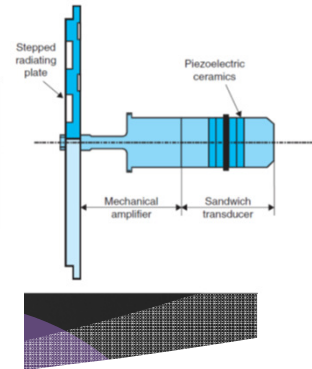
- bactericidal action
- effluent treatment
- modification of growth of living cells
- alteration of enzyme activity
- sterilization of equipment



Processamento por Ultrassom

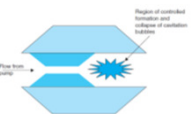
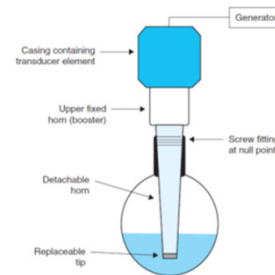
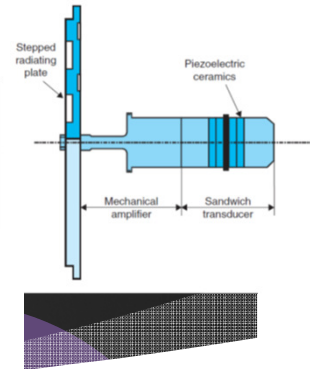
➤ Mistura e homogeneização

- ✓ Maior estabilidade de emulsões resulta em tamanhos de gota menores que a agitação mecânica
- ✓ Diminuição da quantidade de surfactante requerido e melhora em processos de encapsulação



Processamento por Ultrassom

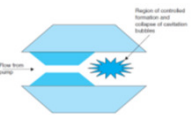
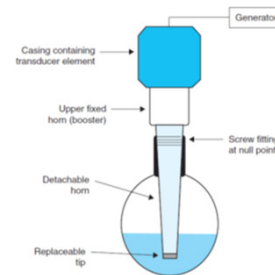
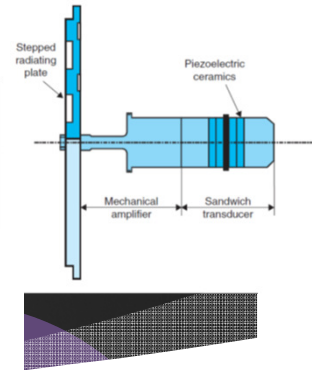
- Formação e destruição de espumas
 - ✓ Redução do uso de agentes antiespumantes
- Precipitação de pós dispersos no ar
 - ✓ Provoca aglomeração das partículas
 - ✓ Pode ser aplicado em ambientes com alta pressão e temperatura



Processamento por Ultrassom

➤ Filtração

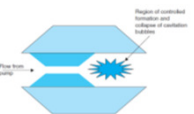
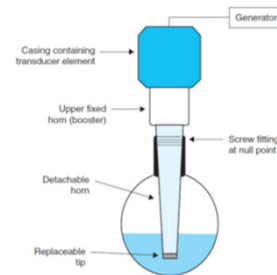
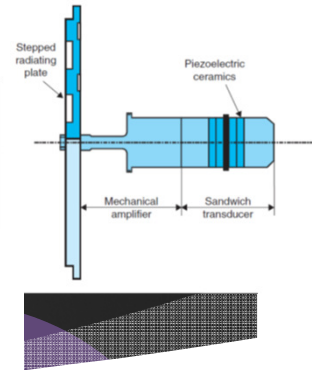
- ✓ Operação mais eficiente do sistema por tempos mais longos
- ✓ Aglomeração das partículas mais finas e manutenção de partículas suspensas evitando o entupimento da membrana
- ✓ Filtração eletroacústica



Processamento por Ultrassom

➤ Secagem

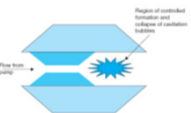
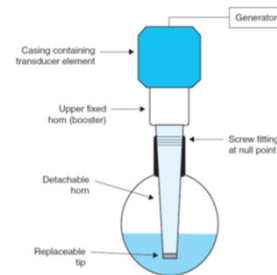
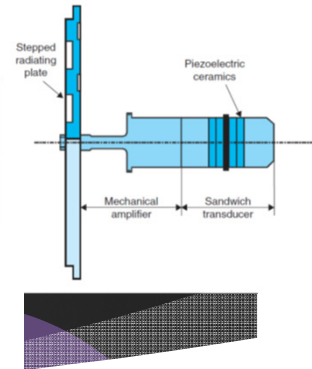
- ✓ Diminuição da temperatura e do tempo de processo
- ✓ Na desidratação osmótica favorece a transferência de massa



Processamento por Ultrassom

➤ Extração

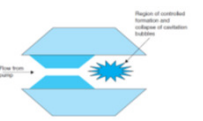
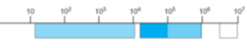
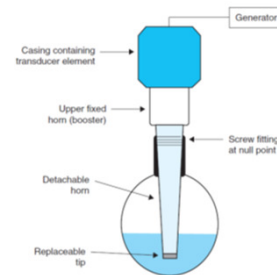
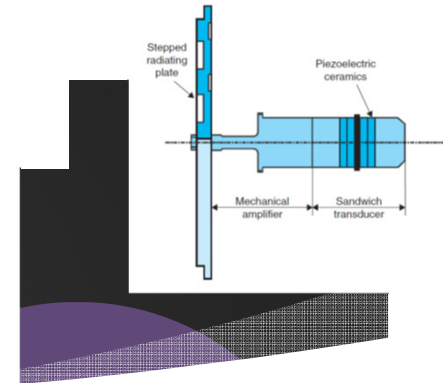
- ✓ Favorece a penetração do solvente no produto e a transferência de massa nas interfaces
- ✓ Difusão de conteúdo celular pela ruptura das membranas
- ✓ Combinação com micro-ondas e extração supercrítica



Processamento por Ultrassom

Table 13.3 Application of acoustic energy in the drying of food

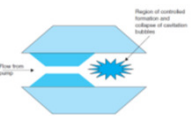
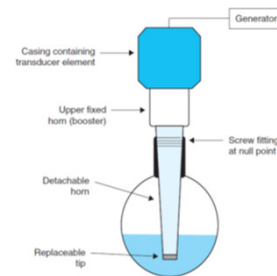
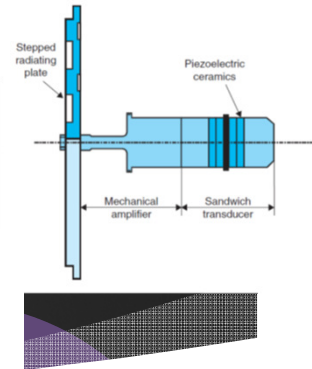
Material	Assisted drying procedure	Reference
Gelatin; yeast cake; granulated sugar	Airborne radiation in solid-gas system	Brun and Boucher (1957) Boucher (1961)
Grated cheese; orange crystals; gelatine beds; rice grains	Airborne radiation in solid-gas system	Soloff (1964)
Potato cylinders	Airborne radiation in solid-gas system	Bartolome et al. (1969)
Rice	Airborne radiation in solid-gas system	Muralidhara et al. (1985)
Apple cubes	Hypertonic solution of sucrose in solid-liquid system	Simal et al. (1998)
Cheese cylinders and parallelepipeds; curd	Saturated NaCl brine in solid-liquid system	Sánchez et al. (1999)
Onions	Airborne radiation in solid-gas system	Da Motta and Palau (1999)
Carrots	Airborne radiation and direct contact in solid-gas system	Gallego et al. (1999b)
Carrots; apples; mushrooms	Airborne radiation and direct contact in solid-gas system	Riera et al. (2002b)
Apple slices	30° Brix solution of sucrose in solid-liquid system	Cárcel et al. (2002)
Pork loin slices	Saturated NaCl brine in solid-liquid system	Cárcel et al. (2003)
Apples; potatoes	Ultrasonic vibration in direct contact in solid-gas system	de la Fuente et al. (2003)



Processamento por Ultrassom

➤ Efeito do ultrassom em sucos

- ✓ Alterações de viscosidade e sabor (suco de tomate)
- ✓ Pouca redução no conteúdo de ácido ascórbico (suco de laranja)
- ✓ Degradação de açúcares que pode causar escurecimento não enzimático



Processamento por Ultrassom

➤ Efeito do ultrassom em produtos lácteos

- ✓ Homogeneização dos glóbulos de gordura do leite
- ✓ Alteração de coloração e sabor de cozido no leite
- ✓ Modificação das proteínas do leite que resulta em melhor qualidade do iogurte produzido com leite submetido ao ultrassom (MTS)
- ✓ Leite tratado por ultrassom (MTS) não coagula na produção de queijo

