Title	Ultrasound assisted cleaning of ceramic capillary filter
Author(s)	Pirkonen, Pentti; Grönroos, Antti; Heikkinen, Juha; Ekberg, B.
Citation	Ultrasonics Sonochemistry - in press
Date	2009
URL	http://dx.doi.org/10.1016/j.ultsonch.2009.10.016
Rights	Copyright © 2009 Elsevier B.V. This article may be downloaded for personal use only

Article to special issue of Ultrasonic Sonochemistry

ULTRASOUND ASSISTED CLEANING OF CERAMIC CAPILLARY FILTER

Pirkonen, P*., Grönroos, A*., Heikkinen, J*. and Ekberg, B**,

* Technical Research Centre of Finland (VTT)
** Larox Oyj, Finland

Key words: ultrasound, cake filtration, cleaning, ceramic filter

Abstract

Research in the fields of filtration and dewatering connected with the use of ultrasound (US) has been carried out mainly with small laboratory-scale batch or continuously operating devices. So far the only large scale industrial cake filtration applications have been developed and manufactured by Larox Oyj for mining industry. These applications apply ultrasound for cleaning of ceramic capillary action elements having at maximum total filtration area of approximately 150 m^2. Several hundreds of filter units have been delivered worldwide during the past two decades.

1. Introduction

A wide range of studies has been carried out to enhance membrane and particle filtration by utilising ultrasound technology. Studies have been performed mainly in lab or pilot scale, but only very few applications have been proceed to large commercial use. The efforts have been focused on changing suspensions properties to more favourable for filtration and or preventing fouling substance to stick the filter surface or cleaning the filter element itself. Combinations of ultrasound, electric field and washing chemicals have been used [1]. Only four applications which are worth mentioning are electro-acoustic dewatering press (EAD), CERTUS- polishing filter, Scamsonic screening filter and CERAMEC-ceramic capillary MF-filter [1,2,3]. The two cases mentioned the latest have found industrial use.

In this paper the development of ultrasound cleaning of CERAMEC-filter will be presented as a case story. General issues dealing with the applying of ultrasound will also be viewed.

2. Ceramic capillary filtration

Ceramec filter discs (Fig. 1a) are patented sintered alumina membranes with micropores that create strong capillary action in contact with water. This microporous filter medium allows only liquid to flow through (Fig. 1b). Filtrate is drawn through the ceramic discs as they are immersed into the slurry bath, and a cake forms on the surface of the discs. Despite an almost absolute vacuum, no air penetrates the filter media (Eq. 1). Consequently, Ceramec filters require only a small (2.2 kW-CC 45 and 7.5 kW-CC144) vacuum pump to transfer filtrate from the discs to the filtrate receiver. This is in strong contrast to conventional vacuum filters that have high air flow through the filter cake, and need a large vacuum pump. Filter cake is removed from the ceramic discs by scrapers, eliminating the need for compressed air snap blow off [2].

The pore diameter for the air flow through the plate can be calculated by the Young-Laplace Law:

$$D = 4\tau \cos(\theta) / \Delta P \quad (1)$$

τ surface tension for water (N/m)
ΔP bubble point pressure (N/m^2)
θ wetting angle
D pore diameter (m)

The pressure difference needed to draw water out of capillary is presented in table 1. As an example 1.4 bar (= 140 kPa) pressure difference is needed to get water through a capillary having 2 µm pore diameter [2].

3. Ultrasound assisted cleaning of ceramic filter element

The physical effects of acoustic cavitation derive from the formation, growth and implosive collapse of bubbles in liquids irradiated with high-intensity ultrasound that produce intense local heating and high pressures with very short lifetimes. Cavity collapse near a solid surface becomes non-spherical, drives high-speed jets of liquid into the surface, and creates shockwave damage to the surface. Cavitation and shockwaves produced during ultrasonic irradiation of liquid-powder slurries can accelerate solid particles to high velocities [4]. Microscopic contaminants are best removed by lower frequency ultrasound, while submicroscopic contaminants are often best removed by ultrasound at higher frequencies [5].

Ultrasound has been used for cleaning a variety of materials from dental instruments to steel strip. Ultrasonic cleaning generally uses a frequency in the range of 16–70 kHz (Fig. 2) [6]. Higher frequencies, on the order of 400–1000 kHz, have been used very successfully in the silicon wafer industry to clean microscopic particles from wafer surfaces. With higher frequency cleaning, acoustic streaming (a large scale movement of fluid), plays a significant role in particle removal. For frequencies in the ultrasonic range, cavitation events and associated shock waves, microstreamers, microstreaming and micro-jets are important in the cleaning of particle-fouled surfaces (Fig. 3) [7, 8].

The predominant fouling mechanisms observed with ultrafiltration and microfiltration membranes are classified into three categories: the build-up of a cake layer on the membrane surface, blocking of membrane pores, and adsorption of fouling material on the membrane surface or in the pore walls. Acoustic streaming mechanism causes bulk water movement toward and away from the membrane cake layer, with velocity gradients near the cake layer that may scour particles from the surface. When a cavitation bubble is near a cake layer surface, microstreaming will result in a dynamic velocity profile that will exert drag forces on particles leading to removal. Micro-jets are formed when a cavitation bubble collapses in the presence of an asymmetry (i.e., a surface or another bubble). During collapse, the bubble wall accelerates more on the side opposite to a solid surface, resulting in the formation of a strong jet of water with an estimated velocity of 100–200 $m\,s^{-1}$. The effective range of micro-jets is on the order of the bubble diameter. The high velocity of micro-jets could effectively scour particles from a membrane surface [7].

Ultrasound assisted cleaning of ceramic filter elements is performed together with back flushing with filtrate or with washing chemical solution (Fig. 4a). Back flushing removes residual cake and cleans the microporous structure. Backflow washing is automatic and adjustable for each application. Examples of possible Langevin type ultrasound transducers which could be installed inside the transducer box are presented in Fig. 4b. US transducer boxes are located between all the ceramic filter discs (Figs 4c and d). Cleaning phase is started when the capacity of filter has dropped below the set value. During the cleaning phase slurry basin is filled with water. Alternatively pulsed ultrasonic cleaning is carried out using the slurry in the filter basin as cleaning medium. In Fig. 5 an example of the effect of ultrasound in a pilot filter filtering iron ore is shown [2, 9].

4. Development of ultrasonic transducer elements

The success in ultrasound assisted cleaning requires excellent transform of electric energy to mechanical vibrations in such a way that erosion of transducers is minimal and electric efficiency is maximal. Planning, design and high quality manufacturing is needed. Long list of issues to be taken care of is needed in the development work: properties of basic ceramic vibrating discs, assembling of individual transducer units, transducer box material, way of connecting ceramic elements to the transducer box, properties of suspension to be filtered, ultrasound frequency, etc…

Impedance analyzer is a good tool to check the electrical properties of the individual transducer elements and transducer boxes (Fig. 6). Scanning laser vibrometer creates proper animation and gives also other info about the quality of vibration of the designed and manufactured transducer surface (Fig 7). Manufactured transducer boxes should also be tested with long term runs in the suspension to be filtered (Fig. 8a). Testing will straight reveal the errors in design of transducer box and severe erosion may appear (Fig. 8b) [9].

The durability of the ultrasonic transducers is important. Good service life can be achieved by using more cavitation resistant materials or by improving the manufacturing methods to minimize variations in the products. It is also important to achieve an even cleaning of the whole surface of the filter elements and therefore the ultrasound emission intensity from the ultrasonic transducer surface has to be well controlled.

5. Application of ceramic filters

The capillary action dewatering system is exceptionally efficient for applications in the mining industry. The filter disc material is resistant to most chemicals, and it has a long operational life. Ceramec filters are best suited for dewatering of slurries with high and consistent concentration of solids having the major part of the particles in the size range 30-150 microns, The Ceramec filter technology is used widely for dewatering base metal concentrates, ferro chrome and iron ore products. Areas of application concentrates: Copper, Nickel, Zinc, Lead and Pyrite. The biggest machine is CC-144 which has filtration area of 144 m^2 (Tab. 2). Industrial installation can also include several Ceramec units (Fig. 9). Several hundreds of filter units have been delivered worldwide during the past two decades. The benefits of Ceramec filters are: very low energy consumption, dry filter cake, particle free filtrate, high filtration rates simple installation, operation and maintenance, integrated filter and ancillaries system, continuous operation, and high availability [10].

6. Future prospects

Ultrasonic cleaning of filter elements is an important issue in capillary action filtration in order to keep the filtration rate on a high level. Further development aims at finding ways to obtain maximum cleaning efficiency especially in processes with changing conditions. To achieve this development of methods for on-line measurement and adjustment of the ultrasound efficiency during filtration must be developed.

Literature

[1] P. Pirkonen. Ultrasound in filtration and sludge dewatering, Advances in Sonochemistry vol. 6, Ultrasound in environmental protection (eds. Mason, T. and Tiehm, A.), Jai Press Amsterdam (2001) 221-246.

[2] Larox Ceramec Filters, Larox Corporation 2007.

[3] Scamsonic filter 2009, www.priorindustries.com/brochures/brochure_1.pdf .

[4] K. S. Suslick et al., Acoustic cavitation and its chemical consequences. Phil. Trans. R. Lond. A 357 (1999) 335-353.

[5] D. H. McQueen, Frequency dependency of ultrasonic cleaning, Ultrasonics, Volume 24 Issue 5 (1986) 273-280.

[6] E. Harman and J. Lamm, The Impact of Ultrasonic Frequency on Particle Removal, Branson Ultrasonics Corp.).

[7] M. O. Lamminen et al., Mechanisms and factors influencing the ultrasonic cleaning of particle-fouled ceramic membranes, Journal of Membrane Science 237 (2004) 213-223.

[8] M. O. Lamminen et al., Cleaning of particle fouled membranes during cross-flow filtration using an embedded ultrasonic transducer system, Journal of Membrane Science 283 (2006) 225-232.

[9] A. Grönroos, P. Pirkonen, H. Kyllönen, SOME APPROACHES TO THE SCALE UP OF ULTRASONIC PROCESSING BY VTT IN FINLAND Special Session of ICA in Madrid 2-7th September 2007 on “High power ultrasound in large-scale sonochemical reactors".

[10] Filtration Solutions for Mining and Metallurgy, Ceramec Capillary Action Disc Filters 2006, www.larox.com

Table 1. The pressure difference needed to empty pores of different diameters. Surface tension of 0.070 N/m and cos (θ) = 1 have been used [2].

D, μm	8	4	2.5	2.3	2	1.5	1	0.5	0.3
ΔP, kPa	35	70	112	122	140	187	280	56	933

Table 2. Properties of different Ceramec capillary filters [2].

Model	CC-6	CC-15	CC-30	CC-45	CC-60	CC-144
Av. power usage (kW)	4	9	14	17	27	70
Installed power (kW)	6.4	14.5	28	30	44	110
Basin volume (m^3)	1.7	3.1	5.2	7.4	9	35
Weight (ton)	4	7.1	9.8	13.8	15.1	34
Height (mm)	2600	2700	2700	2750	3000	4780
Width (mm)	3050	3300	3300	3300	3420	5900
Length (mm)	2700	4050	5600	7040	8750	8570
Filtration area (m^2)	6	15	30	45	60	144

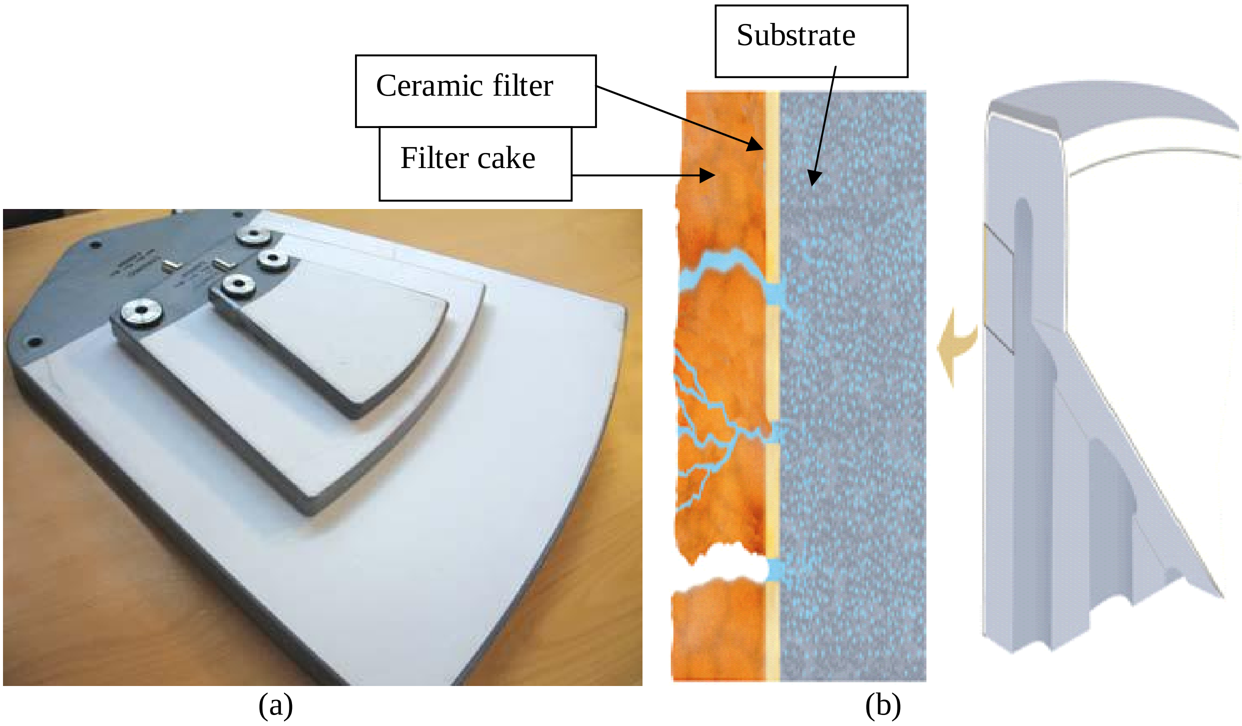


Figure 1. a) Examples of Ceramec filter plates, (b) basic idea of Ceramec filtration [2].

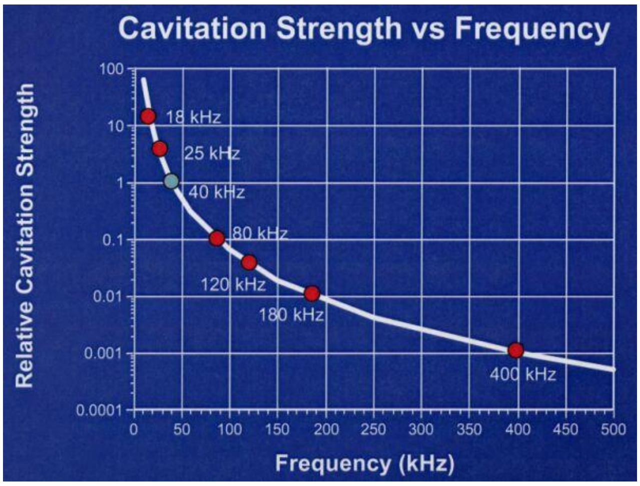


Figure 2. Cavitation strength vs. ultrasound frequency [6].

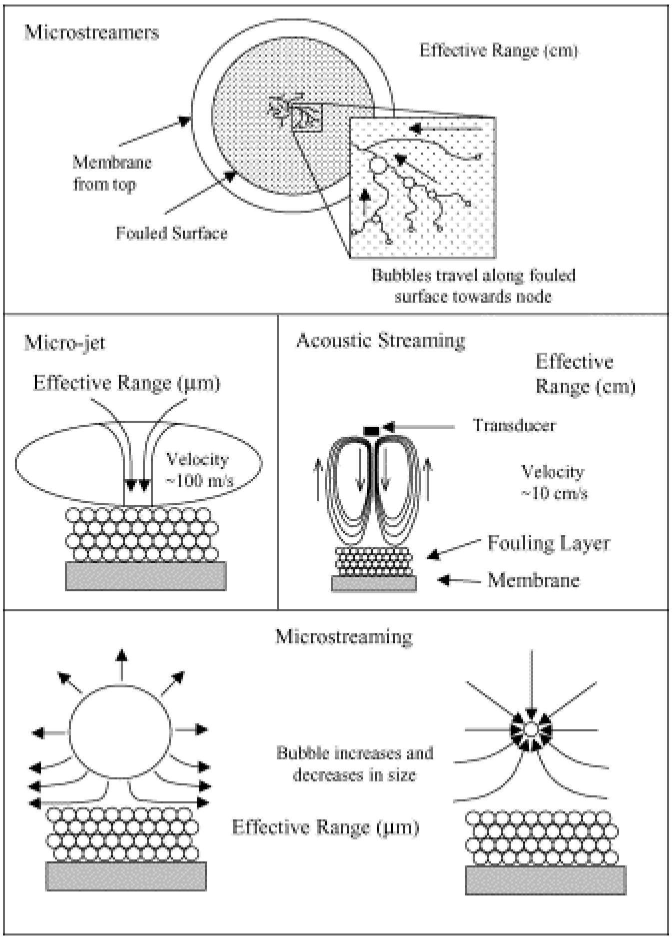


Figure 3. Possible mechanisms for particle removal/detachment observed with ultrasonic cleaning [7].

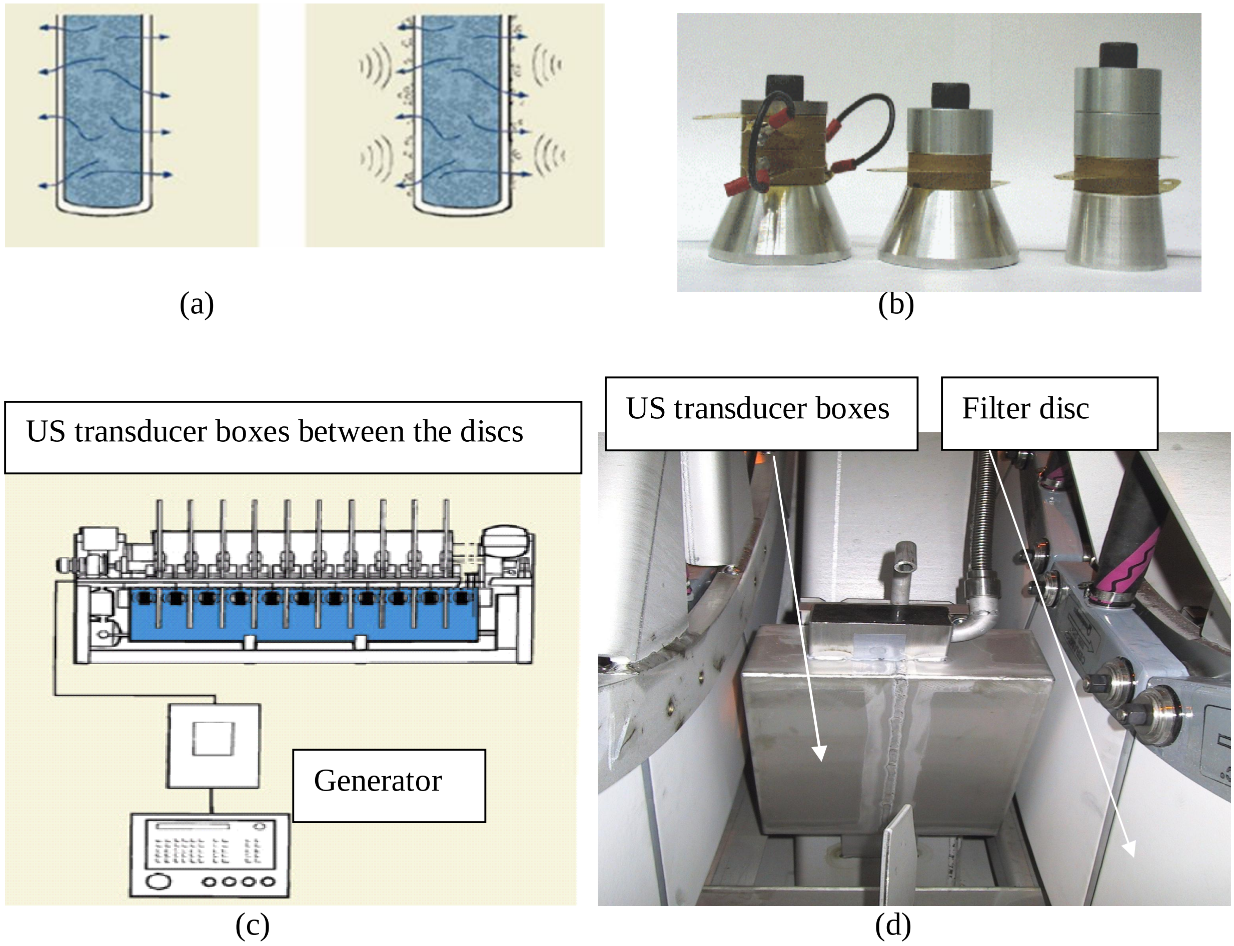


Figure 4. a) Principle of ultrasonic cleaning, (b) examples of possible Langevin type ultrasound transducers which could be installed inside the transducer box, c) and d) placing of transducer boxes in the filtration machine [2, 9].

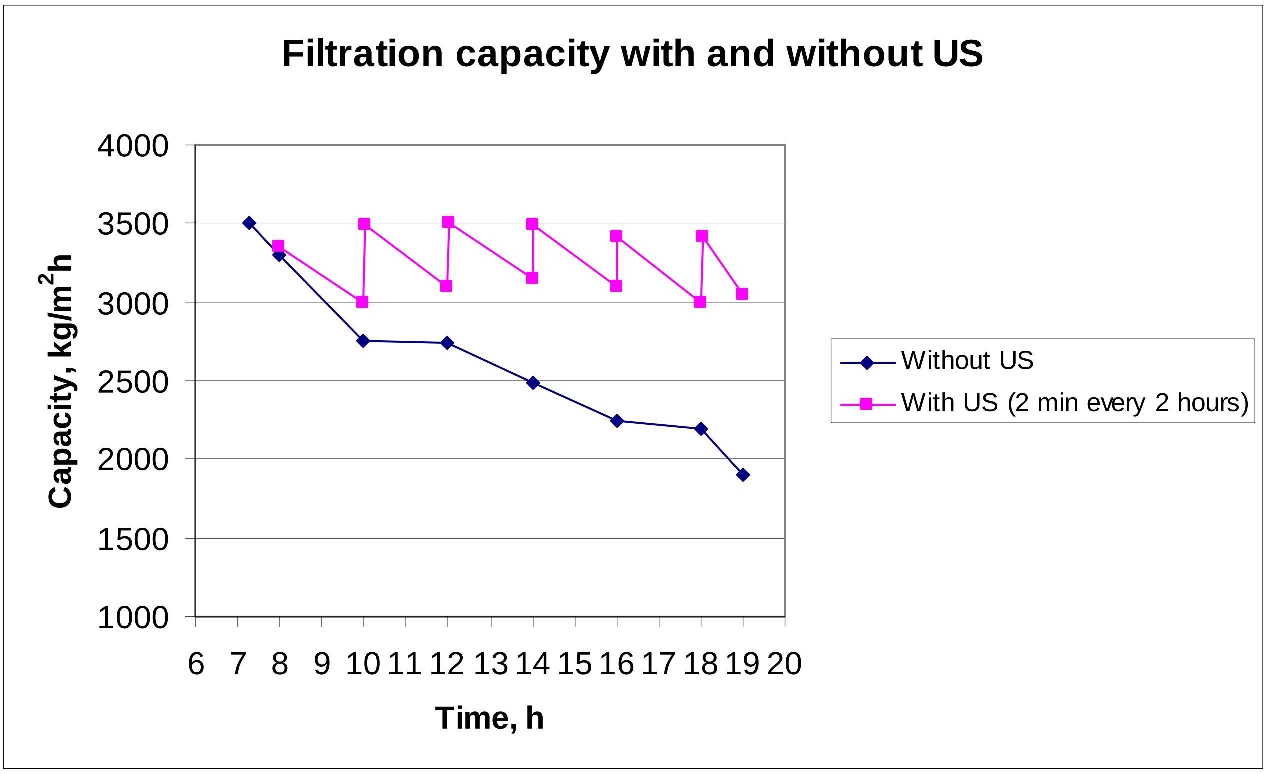
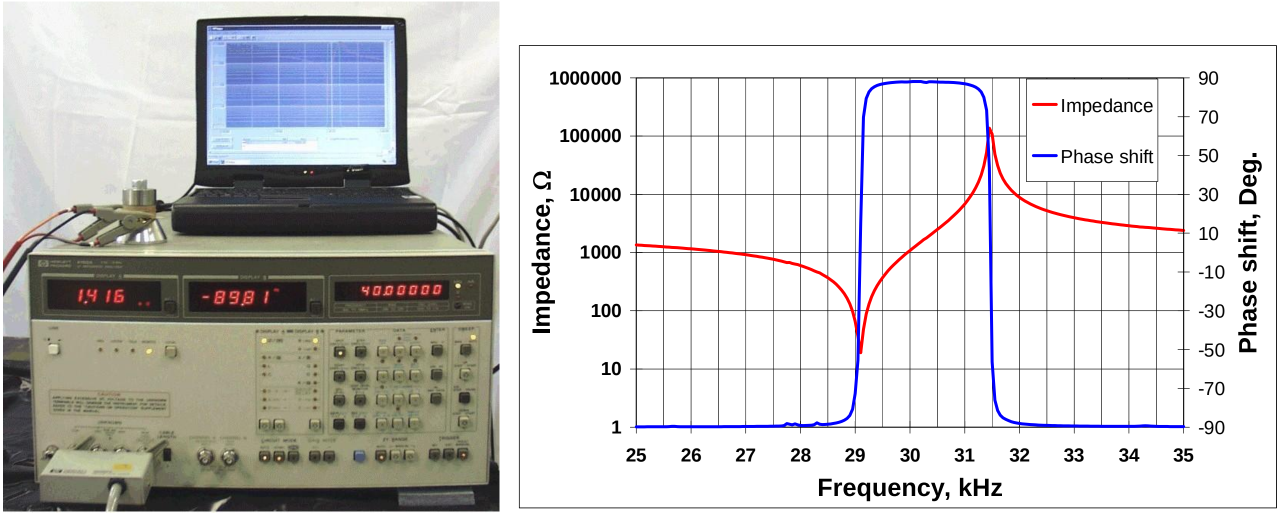


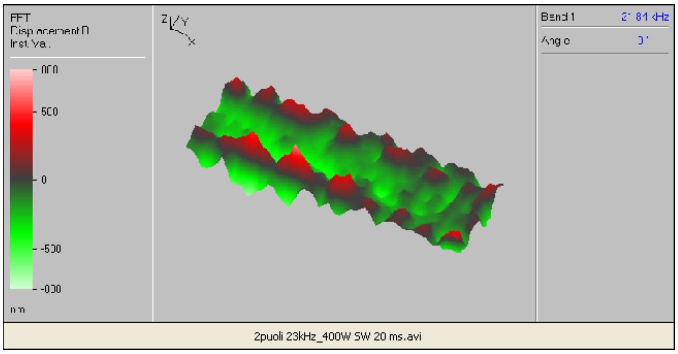
Figure 5. Filtration capacity as a function of time with and without pulsed ultrasonic cleaning in a pilot scale capillary action filter. The length of the ultrasonic pulse is 2 minutes and the interval is one hour.



(a) (b)

Figure 6. a) Impedance analyzer, b) impedance and phase shift figures as a function of US frequency [9].

(a)



(b)

Figure 7. a)Scanning laser vibrometer, b) height of surface vibrations in a transducer box [9].

(a) (b)

Figure 8. a) Long term testing of ultrasound transducer boxes, b) erosion of ultrasound transducer box [9].

Figure 9. Industrial installation of Ceramec capillary filters which have ultrasonic cleaning system [10].