An ultrasonic prototype to remedy pipes clogging: experimental effects on drains used for landslide mitigation

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AN ULTRASONIC PROTOTYPE TO REMEDY PIPES CLOGGING: EXPERIMENTAL EFFECTS ON DRAINS USED FOR LANDSLIDE MITIGATION.

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ABSTRACT

In many cases it is observed that drains or piezometers used in hydrogeology or landslide mitigation, often of considerable cost, may partly or wholly lose their function - even in few months - due to phenomena such as scaling, fouling, corrosion, etc. Several techniques are already available to overcome these problems, but none of these proved to be decisive and effective in every situation. The use of ultrasonic technology in this context has certainly highlighted the complexity of the physical and chemical phenomena that characterize these kind of problems. Analyzing the results obtained from tens of laboratory tests, it was noted that there are several factors that play a rule and that can somehow influence the effect of ultrasonic waves in removing fouling. However, it was highlighted that for small diameter drainage (< 10 cm in diameter) applications using continuous or pulse frequencies of 25-20 kHz can give amazing results. The action of these mechanical waves would result in the removal of impurities from solid surfaces. Any foreign object lodged or firmly anchored to the internal or external surface of the drain is broken down and crushed by ultrasonic waves. The forecasts for their useful application are optimistic: the working time was estimated, from laboratory tests, in the order of tens of seconds per meter so the time this technique should takes for the operation of cleaning in real cases would be almost 1-2 hours for each drain, depending - of course - on length, nature and severity of clogging.

Keywords:

Drains, ultrasounds, clogging, landslide, mitigation

1. INTRODUCTION

The technique of ultrasonic waves for cleaning is already widely used in industry in various fields with good results and provides better results than traditional techniques, particularly in the case of microporosity; does not introduce external agents, such as disinfectants and acids; and does not require direct mechanical action. Currently, most ultrasonic cleaning systems involve the use of a basin, in which objects are immersed to be cleaned, where the process duration time ranges from minutes to hours. The innovation of this study consists of creating a system that can be used on-site (field) in tubular objects, which are tens of meters in length, such as sub-horizontal and vertical drains, wells, and drainage. This system can be effective within a reasonable amount of time (few tens of seconds per meter to remove pipe fouling). In the past, other researchers have performed similar experiments to clean tubes of different dimensions and for different purposes (Clarence et al., 1990; Hoffjann et al. 1997; Turievskij G., 1977).

Regarding the application of this technique in engineering geology, drainage systems currently represent one of the techniques used to stabilize slopes (Cano M. & Tomàs R, 2013) because it is well known that water is one of the most important predisposing and triggering factors for landslides. In the design of a landslide mitigation project, it is therefore essential to plan effective systems for the drainage and subsequent removal of excess water from the landslide. It is also crucial to ensure proper maintenance of the mitigation works for many years. In fact, the duration and efficiency of these drainage systems are closely related to the maintenance of the entire system. Moreover, it is also particularly important that the techniques used to "clean" and restore the works themselves are unaffected by fully or partial clogging. A drainage pit or a system of sub-horizontal drains requires **(figs. 1 and 2)**, for example, a costly investment that must be justified by an equally long operating life (Hutchinson J.N., 1977). The exact same problems occur in wells or in the maintenance of pipes and sewers.

Certain situations are more problematic for drains than others. In particular, in our experience (Mandrone G., 2006), one critical situation is in sub-horizontal drains in northern Apennines and in western and southern Piedmont (North Italy), where heterogeneous rock masses are widespread: in these areas, only a few months are needed to completely block every type of drain (with small or large windows, with or without geotextile). The presence of fine materials (clays) and groundwater rich in carbonates are typically the causes of these problems.

The technologies developed to remedy clogging of these types of works are many and varied, which is a testament to their technical pressing need and their lack of efficiency in different conditions.

In the cases studied here, generally, drain clogging is so intense that each effort to restore their functionality does not work and it cripple in a few months.

Fig 1 – Example of sub-horizontal drain outlet, where partial clogging of several pipes can be observed.

a) b)

Fig 2 – Example of drains used in boreholes: a) pipes with transversal slotting, b) perforated pipe covered by a geotextile.

2. CLOGGING IN DRAINS/WELLS AND CONVENTIONAL RECOVERY TECHNIQUES

The hydraulic efficiency of drains and wells generally tends to diminish over time. This process, called "aging", is due to a number of causes of chemical, biological, geological and mechanical origin. The primary causes are scaling and corrosion. In general, water of all chemical types is corrosive (removes metal from the surface of pipes or other metal tools) and causes scaling (deposits of solid material on pipes and filters). In a combined action of these two phenomena, it is also possible that fouling "protects" pipes from corrosion.

Corrosion can enlarge the slottings of filters (thus allowing the passage of sand) and locally reduce the thickness of the casing (that can consequently cause crushing), whereas the deposition of corrosion products on filters results in their partial or total blockage. Scale can be hard and brittle, be similar to flakes of concrete or be of soft, muddy or gelatinous consistency.

Clogged filters in many areas of Northern Italy are often due to precipitation of carbonates present in groundwater, particularly those of calcium carbonate, near the casing filters. Other substances, such as silicate of aluminium and iron compounds and suspended particles can be incorporated within these deposits. Other causes of failure can be found in the production of sludge as a result of the life cycle of iron bacteria and deposition of clay or silt carried in suspensions by water.

The cycle of chemical and physical processes that causes scaling is extremely complicated and difficult to predict, though, in general, scales increases with an increasing content of carbonates and iron in water. The situation worsens if there is a meaningful increase in lowering the water level in the well and if there is an increase in water flow through the filters.

Traditional techniques used in the restoration of wells and drains are many, which reflects the fact that the maintenance or "cleansing" of these works is crucial to allow their proper functionality. Another reason for the existence of so many techniques is that each of them exhibits certain defects or problems, and in fact, traditional techniques are not always effective in every case. The most common systems (Pérez-Paricio, 2001) are summarized in **table 1**.

<table>
<tr><th>TYPES OF “CLEANING”</th><th>DESCRIPTION</th><th>DISADVANTAGES</th></tr>
<tr><td>Acidification</td><td>Use of acids or other chemicals.</td><td>- chemical reactions are not always controllable
- is difficult to the assure that the chemical process acts in the whole encrusted area
- may have strong effects in calcareous geological formations.</td></tr>
<tr><td>Jetting-Tool</td><td>cleaning system using water at high pressure</td><td>limited operating area so may exclude some encrusted areas</td></tr>
<tr><td>Air–lift</td><td>two columns, one inside the other, that allow the release of large quantities of water from the well by blowing compressed air</td><td rowspan="2">- the two techniques need to be combined and alternated during operations;
- need high level of water in the well and medium-high flow of water</td></tr>
<tr><td>Wash–back</td><td>use the shirt as well as ejector column; blowing air in large quantities from the bottom of the well, there is a natural upward pressure water</td></tr>
<tr><td>Pistoning</td><td>the piston, usually a cylindrical shaft, moved by a winch to the surface through a wire, is slid along the filtered shaft of the column</td><td>drains and wells interested by colonies of bacteria or mucilage are not affected by the piston if not in the restricted field of the well column</td></tr>
<tr><td>Brushing</td><td>similar to the pistoning, use a cylindrical shaft as a support for steel brushes</td><td>- do not use in Johnson or similar sand filters
- does not apply to old wells and / or to particularly corroded columns</td></tr>
<tr><td>Hybrid Treatment</td><td>Aqua Freed ® (high-pressure release of carbon dioxide) and Hydropuls ® (release of highly compressed gas or liquid)</td><td></td></tr>
</table>

Table 1 - Overview of the commonly used techniques to clean drains and wells.

3. THE ULTRASOUND CLEANERS

Ultrasonic waves are high-frequency mechanical waves. Unlike true acoustic phenomena, the frequencies that characterize the ultrasonic range is higher than the average audible range of a human ear. The frequency conventionally used to discriminate sonic waves by ultrasonic waves is set at 20 kHz (**Fig. 3**).

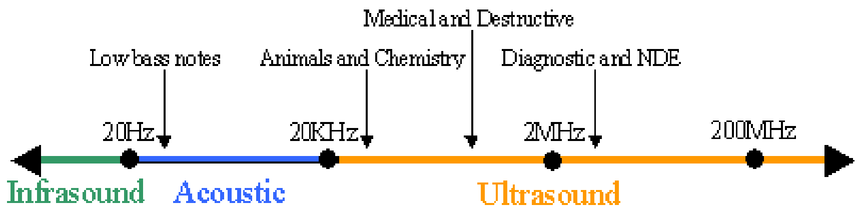

Fig 3 - Corresponding to the approximate frequency ultrasound according to their scope.

Ultrasonic cleaners are used at frequencies from 20 to 40 kHz for jewellery, lenses and other optical parts, watches, dental instruments, surgical instruments, diving regulators and industrial parts. In cleaning equipment, tanks are generally used, in which the tools are positioned and treated for short or long periods. Ultrasonic generators function mostly by energy released from the collapse of millions of microscopic cavitations near the dirty surface. The bubbles made by cavitation collapse, which form tiny jets directed at the surface.

Ultrasonic waves, like any other type of wave, are subject to phenomena of reflection, refraction and diffraction and can be defined by parameters, such as frequency, wavelength, propagation velocity, intensity (measured in decibels) and attenuation (due to acoustic impedance of the medium crossed). Moreover, the spread of energy from the source, due to the shorter wavelength, essentially corresponds to geometric optics (rectilinear propagation, formation of shadow zones) and can have an high value of radiation intensity (proportional to the square of the frequency and amplitude), which is particularly important for absorption in various media.

The generation of ultrasonic waves occurs through the use of transducers used in conditions of resonance that can radiate at a single frequency or harmonic frequencies with less intensity. Ultrasound results in the following principal effects:

a) heat - when an ultrasonic wave propagates, the width of the wave is progressively reduced, which yields some of its energy as heat, particularly at the interface between materials with different acoustic impedances;
b) mechanical - the passage of a wave in a medium determines the oscillation of particles that oscillate at the same acceleration and speed of the ultrasonic beam.
c) cavitation - the formation and then immediate implosion of cavities in a liquid, which are consequences of forces acting upon the liquid, and usually occurs when a liquid is subjected to rapid changes of pressure that causes the formation of cavities where the pressure is relatively low.

In particular, non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often used in ultrasonic cleaning baths and can also be observed in pumps, propellers, etc.

Regarding a hydraulic device, to ensure fluid cavitation, it is essential that there is a presence of gas nuclei and a pressure that even locally, is equal to the value of vapour pressure. Microscopic gas bubbles that are generally present in a liquid are forced to oscillate due to the applied acoustic field. If the acoustic intensity is sufficiently high, bubbles will first grow in size and then rapidly collapse. Cavitation inception (**fig. 4**) occurs when the local pressure falls sufficiently far below the saturated vapour pressure, which is a value based on the tensile strength of the liquid at a certain temperature. Note that temperature has a direct and considerable influence on the cavitation because it distorts the vapour pressure.

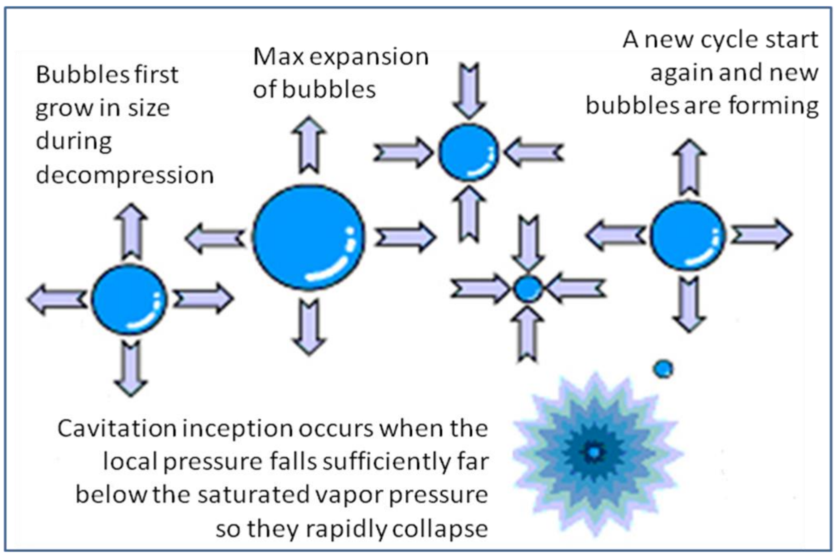

Fig. 4 – Sketch of the cavitation process.

Ultrasonic generators are sinusoidal alternating waves of static converters and work in single or three-phase alternating current (Gilmore, 1989). The input power from a generator is calculated by the following formula:

$$P = V \times I \times \cos \varphi \text{ (Single-phase AC power)}$$

$$P = 1{,}73 \times V \times I \times \cos \varphi \text{ (Three-phase AC power)}$$

where the voltage (V) and alternating current input (I) are multiplied by the cosine angle of the alternating phase shift (cos φ).

Therefore, the actual power consumption (P) from a generator is not a valid parameter to define the effective cleaning power (PEP) of a washing system with ultrasound. In fact, this value should be considered by the quality of the electromechanical transducers and their performance, type of amplifier output, type and uniformity of the emitted electron waves and their form and synchronization with transducers, quality and uniformity of the mechanical waves that are actually transmitted at the liquid, etc.

The ultrasonic generator power required to create cavitation is generally, but not always, directly proportional to the frequency. In general, more uniform penetration occurs at high frequencies (> 40 Khz). In the high-frequency range, there is a more powerful mechanical-molecular vibration that compensates for the lack of impact energy characteristic of lower frequencies, e.g., approximately 20 kHz (Lucas & Chapman, 1989). Therefore, it is essential to continuously vary the frequency of the wave or the origin of the source to prevent the formation of "nodes" created when the wavelength remains fixed at the same point in time. In these nodes, there is no erosion of the material to de-scale; however, there is also the formation of standing waves (spurious) that removes a substantial part of the wave energy.

In our experiments, the transducer is the element that can transform energy from electrical to mechanical noise. The transducer is a vibrant tool that produces an amplification of the intensity of vibration and also has the function of homogenizing the ultrasonic waves or eventually, concentrating them at a given point.

4. LAB TESTS ON DRAINS

It is theoretically possible to apply such systems to "clean" and rehabilitate wells, pipes and drains. The problem is that these objects are placed deep into the ground (tens of meters), which can be difficult to access, and thus, these system must be able to operate only from the surface.

In the labs at the Dept. of Earth Science of Turin University, it was possible to reproduce, in scale, natural processes of clogging and to test ultrasound equipment with the purpose of recovery the functionality of drains. The equipment used in the experiments included the following:

- electric generator;

- source of ultrasonic waves with regulation of operation time and energy;
- transducer that transforms electric waves into mechanical movement;
- metallic sonotrode that transfers the impulse to the water;
- cable connecting transducer and generator;
- steel cable able to move the sonotrode in the pipe;
- transparent tank to test equipment with different type of drains and to observe (photographs and recordings) the physical effect of ultrasound on drains.

With ultrasonic frequencies, it is possible to obtain the break-up of a wide variety of materials. In the tests, two devices were used with three different cylindrical sonotrodes (**fig. 5**); **table 2** summarizes the characteristics. These particular types of transducers generate a nearly symmetrical and radial (around the transducer) field pressure, which theoretically provides a uniform and effective washing of the wells and drains.

Fig. 5 - Weber Ultrasonic (sx) Sirius Electric (dx) sonotrodes used in lab tests.

ID	Supplier	Power of generator [Watt]	Resonant frequency [KHz]	Power of tranducer [Watt]	Lenght and diameter of sonotrode [mm]	Material of sonotrode
W1	Weber Ultrasonic	2000	25	1500	590; 76	stainless
S1	Sirius Electric	2000	20	2000	380; 49	alluminium
S2	Sirius Electric	1000	36	1000	270; 30	alluminium

Tab. 2 – Description of equipment.

The effect of ultrasonic waves in cleaning drains was tested by artificially clogging the openings of the filters. In detail, several types of commercial PVC filters were tested, referred to as D1, D2 and D3 (characteristic are shown in **tab. 3**). The filters were adequately occluded (**Fig. 6**) with a scale created by filling the filters with a mixture of concrete and silty sand at a ratio of 2:3. After the concrete solidified, the excess was removed; care was taken to leave only the filling of the openings and to check for their full occlusion.

ID	Inside filter diameter (mm)	Width of slotting (mm)
D1	79	0,5
D2	79	1
D3	142	0,5

Tab. 3 – Characteristics of the used filters

Fig 6 – Example of occlusion of the openings (slotting) on filter D1 with a mixture of earth and concrete.

The tests were performed by immersing the drains with the occluded openings in a plexiglass cylindrical tank filled with water at room temperature; the sonotrode was lowered inside the filter, and the drain was exposed to ultrasounds at regular time intervals. At each step, the drain was extracted, observed and photographed. During most of the tests, videos were recorded to observe the effects induced by the clogging.

Photographs were used to reconstruct the effect of ultrasound using an image editing software (Image Tool) that automatically and objectively quantifies the percentage of occlusion/cleaning of the openings. These measurements provide important information not only about how long it takes to completely clean the filters but also which device gives the best results.

Each test was described in detail, which includes information regarding the type of mixture used to clog the filters, power, frequency, absorption and time of the ultrasounds treatments. The ultrasonic pulse was generated continuously at regular intervals, which were several seconds long, by positioning the sonotrode coax to the filter; care was taken to ensure the inside wall of the filter was not touched.

A total of 30 tests was performed with intervals of observations ranging from 5 minutes to 10 seconds by combining different types of devices and filters. The results were evaluated both visually and graphically through image analysis and represented in analytical form. In **fig. 7**, for example, the effects of a 1-minute treatment (3 observations every 20 seconds) on filter D2 with device W1 are shown, including how data were collected and processed. In the top row of the image (A), it is possible to observe the same area of the filter after the various treatments. The same area is presented in row B, elaborated by image analysis: the cleaned openings are highlighted and classified according to their normalized area expressed in mm^2. The same information can be analysed using pie charts (C): in this case, it is possible to quantify the treatment effect.

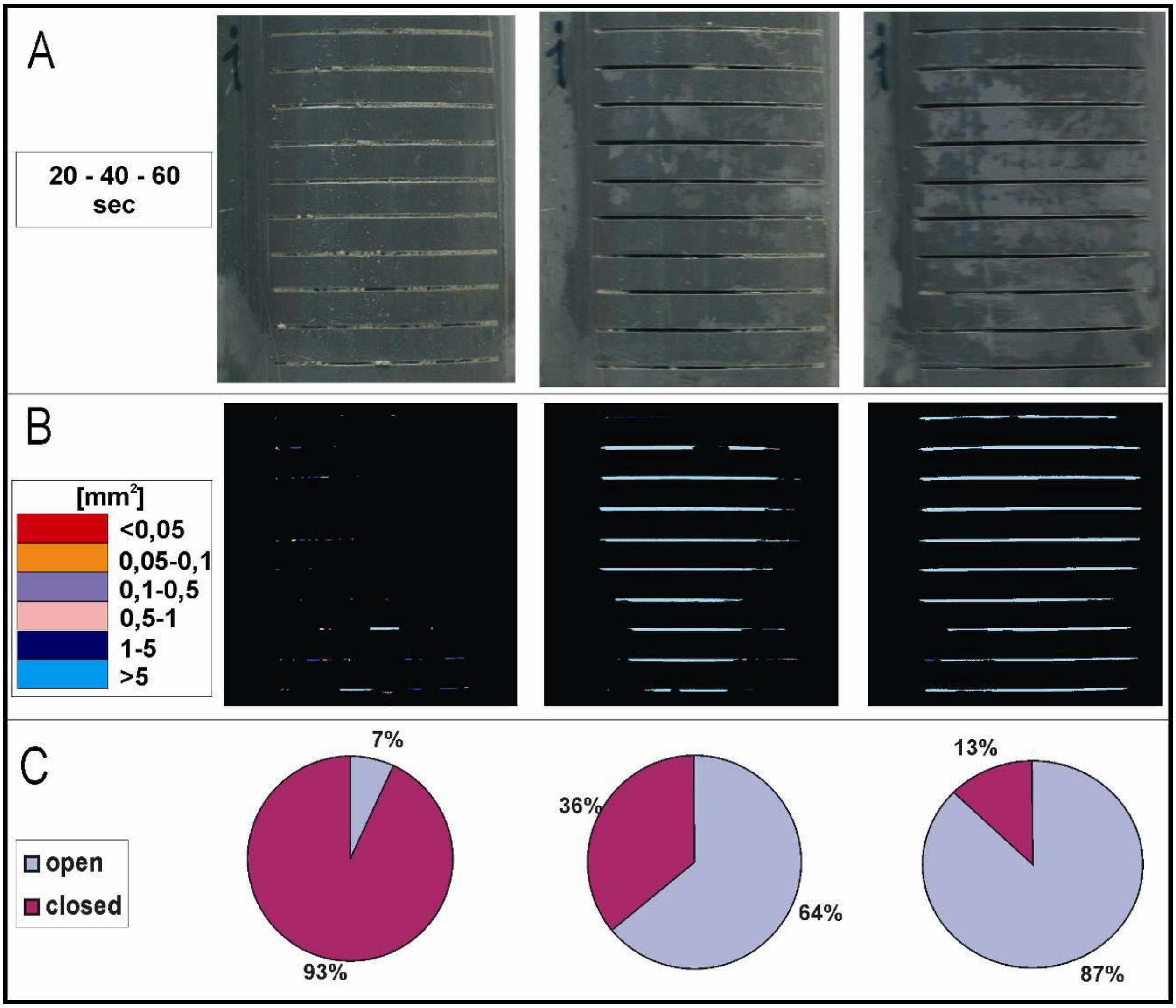

Fig. 7 - Analysis of the effect of ultrasonic waves on filter F2 with device W1 at regular intervals of 20 seconds: A) visual inspection, b) image analysis to quantify the size of open spaces, C) analytical comparison of the windows.

5. DATA PROCESSING

There are substantial differences between drains with smaller diameters and drains with larger diameters. In particular, the effect was immediate in filter D1 and D2, whereas in those with larger diameters (D3), the instrument must be placed closer to the inner surface to be effective.

The study focused on the drains with smaller diameters. In this way, it was possible to show important differences in the cleaning using instruments with different frequencies (20 KHz, 25

KHz and 36 kHz). The last piece of equipment (S2 at 36 kHz) was inefficient for descaling, and so, after preliminary analysis, it was no longer used.

The following tests were performed with W1 and S1 ultrasound devices, D1 and D2 drains and different times of exposure to ultrasounds. In detail, instrument W1 (25 kHz) on drain D1 (**fig. 8**) after 15, 30 and 45 seconds obtained a percentage of cleaning of approximately 30%, 55% and 81%, respectively; the trend is regular such that it is possible to affirm that every 15 sec, the portion of cleaned opening increased by 25%. Using filter D2, after 10 and 20 seconds, only 1% and 7% of the filters was cleaned, whereas there was a large jump from 20 to 30 s, when the cleaned percentage increased to 46% (after 40 s, cleaning reached 64%; after 50 s, cleaning reached 74% and after 1 minute, cleaning reached 87%). With instrument S1 (20 kHz**)** in filter D1, it was observed that after the first 20 sec, a cleaning of approximately 76% of the openings was obtained (much better than previously). The cleaning process was almost complete, more than 90%, after 30 sec. Using filter D2, the effect was already clear after only 10 sec; the cleaning was measured to be approximately 53% and was essentially complete after 30 s (92%).

Comparing these and other data, it seems clear that the capability of cleaning the filters depends on the frequency used (lower is better) but is also influenced by the dimension of the opening of the filters (larger ones are easier to clean), as demonstrated by the fact that the best results were obtained when using frequencies of 20 KHz and with openings of 1 mm of width.

The goodness of the lab test was further verified by the good agreement shown by a simple statistical analysis of the data. Using a logarithmic line of tendency, the coefficient R is always greater than 0.9, which indicates that the cleaning process does not occur as a random phenomenon but follows a precise physical law as a function of time (fig. 9).

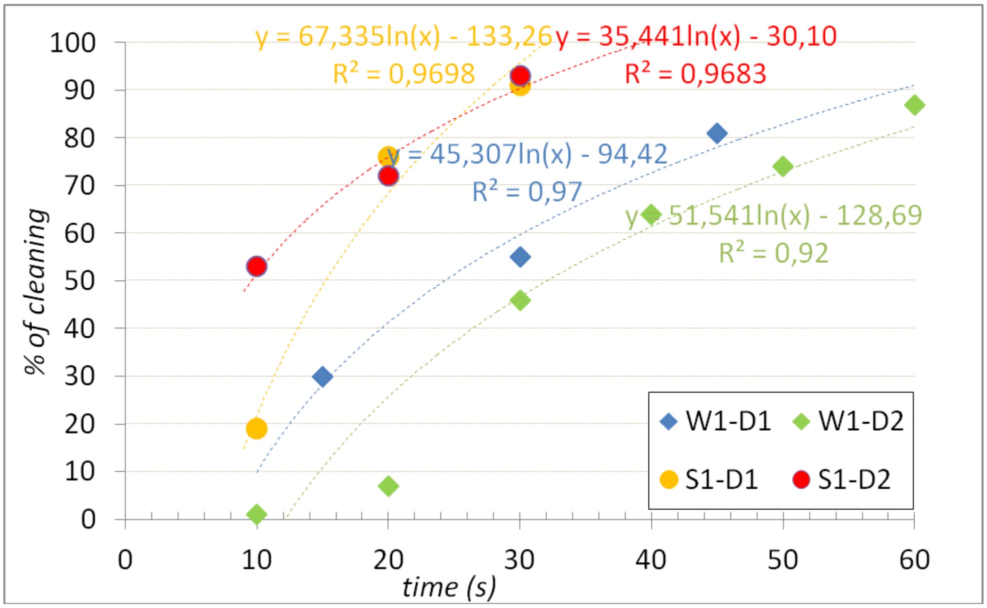

Fig. 8 – Comparisons of effects (% of cleaning) induced by two different ultrasonic devices (W1 and S1) using two different types of filters (D1 and D2) as a function of treatment time.

6. DISCUSSION AND CONCLUSION

Innovations resulting from this study are different and extremely interesting to everybody working in the fields of filters, drains, pipes and wells. Traditional methods used for the rehabilitation of filters are not only ineffective everywhere, even in relation to their costs, but can also be inconvenient or even harmful from an ecological standpoint (such as using acids that can pollute groundwater). However, using technologies based on ultrasound brings benefits in terms of environment and in consideration of the final result, can likely better clean filters affected by scaling than traditional systems.

The action of these mechanical sound waves with frequencies between 20-25 kHz ensures the mechanical removal of impurities from solid surfaces and of any material firmly lodged or anchored to the surface of the filters. Any foreign object is broken and crushed by ultrasound, and it is possible to say that cleaning occurs at a “particle" level.

Another element highlighted by the tests is the relative speed of the method used to descale. The forecasts are optimistic: the working time was estimated, following laboratory tests to be on the order of approximately a meter per minute (a 30-m filter will be recovered in approximately an hour of treatment). Thus, the impact on technical and economic aspects would be extremely positive because as highlighted in the study, the proper operation of drainage works is closely related to their efficient maintenance.

Finally, it was also shown that in situations where a rapid deterioration of the functionality of the filters is expected, it is preferable to use small-diameter drains with wider openings because they were much easier to clean with ultrasound techniques. Further studies will investigate potentialities of this technique in wells of larger diameters (decimetres). However, several technical issues still remain to be resolved for application in practical cases, and prototypes still require upgrades in collaboration with companies and technicians operating in this field.

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