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THESIS

Thesis Summary

Contributions to the design and realization of an air filtration system using ultrasonic cavitation

Ph.D Supervisor

Prof.dr.ing.ec. Vasile BENDIC

Ph. Student

eng. Adrian ISPAS

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Thesis summary

The topic of the doctoral thesis entitled **Contributions to the design and realization of an air filtration system using ultrasonic cavitati**on is briefly presented in this Summary, taking into account the logical sequence of the work's chapters. The doctoral thesis consists of two large parts. The first of them entitled "**SUSTAINABLE DEVELOPMENT, AIR QUALITY AND THE CURRENT STATE OF INDUSTRIAL AIR FILTRATION SYSTEMS**" is intended to present the current state of the proposed topic as well as its framing in the context of current development. The second part entitled "is devoted to the presentation of calculations, design and realization of the experimental system for industrial air filtration using the phenomenon of ultrasonic cavitation.

The first chapter is entitled "**SUSTAINABLE DEVELOPMENT**" contains several sub-chapters from which the essential elements will be selected for presentation.

1.1. Generalityes

At the present time, a very interesting and important phrase has appeared in the common language of mankind and in everyday activities, and it has guided and will guide people's actions for a long time to come. This notion is called „Sustainable-development" which has been and is defined in many ways. All the definitions, however, lead to the same activities of mankind that aim at a planning of economic activities that want to stimulate economic growth but at the same time maintain the quality of the environment for future generations. Although this concept has been circulated a lot in the last two decades of the 20th century, it has proven to be difficult to use often because sustainability studies over a longer period depend on the analyzed resources. Sustainability was the focus of the 1992 Earth Summit and has since been central to a multitude of environmental studies, conferences, analyzes and approaches. In this way, the aim is to find a common point between economic growth and the social and natural environment. In 2001, the European Union established the framework for the sustainable development approach. It is reconsidered in 2006, which provides "a long-term picture for sustainable development for which economic development, social issues and environmental protection are not mutually exclusive but at the same time rely on each other". The review of thinking by the European Commission in 2009 highlighted the reminiscence of unsustainable manifestations and the need for much stronger actions in this regard. However, they highlighted the steps taken before the European Union in including sustainable development in many of the provisions adopted such as trade and economic development and highlighted the initiative taken in terms of climate change and ensuring that countries' economies will lead to lower emissions of carbon. At the same time, historically speaking, sustainable development has since then officially been a long-term goal of the European Union according to Article 3, paragraph 3 of the Treaty on EU.

In 2015, 17 sustainable development objectives were established. They are a call to action to all nations to eliminate poverty, "save" the planet and raise the standard of living and aspirations of people on all continents. The 17 Sustainable Development Goals were adopted by the member countries of the United Nations in 2015, as part of the 2030 Agenda - Sustainable Development. Thus, a 15-year agenda was established for the fulfillment of the proposed objectives. This roadmap is a sequence of actions for the inhabitants of the planet, for it and for its well-being. At the same time, efforts are being made to consolidate peace as much as possible. In this context, it is known that the elimination of poverty in all its forms as well as its size, including extreme poverty, is among the biggest challenges and an essential criterion for sustainable development. The 17 Sustainable Development Goals demonstrate the size and ambition of this new universal Agenda. They are integrated and indivisible and balance the three dimensions of sustainable development: economic, social and environmental.

The 17 objectives of sustainable development are briefly presented as follows:

- **No poverty**;
- **No hunger;**
- **Healthy life and well-being for all regardless of age;**
- **Quality education;**
- **Achieving gender equality and valuing all women and girls;**
- **Ensuring equal access to water and sanitation;**
- **Ensuring access to affordable, sustainable and modern energy;**
- **Promoting sustainable, inclusive economic development, employment and decent work**, in conditions that respect occupational health and safety standards, involves, among other things, ensuring an adequate climate or microclimate, without air pollution. Under these conditions, the research carried out during this doctoral thesis fits very well into this objective of sustainable development;
- **Building a resilient infrastructure, promoting sustainable industry and encouraging innovation -** In this context, the present PhD thesis that

discovers a new industrial air filtration technology with very good results, results that can be further improved, falls into this context;

- **Reducing inequalities**. Reducing inequality within a country and between countries;

- **Sustainable cities and communities, Inclusive, safe, resilient and sustainable cities**; - Also taking into account this requirement of sustainable development, this doctoral thesis tries and succeeds in including elements that contribute to the transformation of cities into sustainable and safer ecosystems;

- **Responsible production and consumption**. Ensuring sustainable models - In this context, it can still be observed that the present research tries to make a small contribution to stopping the degradation of the natural environment by eliminating the old air pollution technologies which in turn pollute the natural environment through the filter elements used;

- **Taking urgent measures to combat climate change and its impact;**

- **Life under water**. Conservation and sustainable use of oceans, seas and marine resources;

- **Life on the surface of the earth;**

- **Peace, justice and strong institutions. Promoting a just, peaceful and inclusive society;**

- **Partnerships for achieving sustainable development goals**. Revitalizing the Global Partnership for Sustainable Development;

One of the most important and current problems of humanity is ensuring a sustainable development of society for years to come. This issue, being so important and complex, currently contains, in order to become applicable, the latest scientific knowledge that can lead to their resolution.

This chapter was designed precisely to include in the objectives of sustainable development the topic of research carried out in order to identify new methods, industrial air filtration technologies. Out of the 17 objectives of sustainable development, the topic addressed, namely the creation of a new system, with superior characteristics, for filtering industrial air can be found in four of the underlined objectives, namely: objective 8- Promotion of sustainable, inclusive economic development, employment of work and decent work, objective 9 - Building a resilient infrastructure, promoting sustainable industry and encouraging innovation, objective 11 - Sustainable cities and communities, Inclusive, safe, resilient and sustainable cities and objective 12 - Responsible production and consumption. Ensuring sustainable models.

The second chapter entitled "**AIR POLLUTION**" is intended for the classifications, the presentation of the effects of this type of pollution on human health, all to argue the need to develop a new industrial air filtration system.

2.1 Generalities. Air pollution on Earth

The definition of air pollution can be found in many forms, but one of the most well-known says that it consists in the release of pollutants into the air. These pollutants harm human health and the planet as a whole. This is a conclusion that holds true in any situation, regardless of definitions. Every year, according to the World Health Organization, air pollution results in nearly seven million deaths across the globe. Around 10% of people are currently breathing polluted air that exceeds WHO limits for pollutants, and those suffering the most are those with low and middle incomes.

Air pollution represents one of the most important, if not the most important, forms of pollution with the most serious, even disastrous, effects on people, animals and the environment. From a scientific point of view, any biological, physical, or chemical change in the atmosphere can be called pollution and occurs when any harmful substance, dust or smoke, enters it, affecting plants, animals as well as human beings. In this way, air pollution implies pollution of the atmosphere and thus any gas or substance entering the atmosphere can create unwanted imbalances in the medium and long term. Therefore, the depletion of the ozone layer in the atmosphere (the one that protects us from the negative effects of ultraviolet radiation) caused by air pollution is a major threat to the existence of ecosystems on the planet and is the ultimate challenge that humanity must overcome despite political differences on the international stage.

One of the main causes is the burning of fossil fuels such as coal, petrol, diesel or gas to produce electricity or facilitate transport. Carbon monoxide emissions at a high level indicate how much fuel is being burned. Inhaling air polluted with these substances reduces the heart's ability to pump enough oxygen and can cause respiratory diseases.

Another source of pollution is represented by industrial emissions, all industrial activities that use wood or coal as a primary source of energy emit pollutants such as nitrogen dioxide, sulfur dioxide and carbon monoxide into the atmosphere. Industrial pollution can have negative health effects such as eye and throat irritation, respiratory problems and can even lead to chronic diseases.

2.1.1 Types of pollution

In the following, several types of pollutants, the most important, which affect life in its most general aspect, will be briefly presented. Among the main causes that lead to air pollution are listed:

- suspended particles which represent a mixture of solid and liquid particles such as carbon, complex organic elements, sulfates, nitrates and water particles. The size of the particles in suspension differ as well as their dimensions, some being larger such as dust or sand on the one hand or smoke which can be observed with the naked eye. Instead, the most harmful are those that cannot be seen with the naked eye because they have microscopic dimensions, being defined as PM 10 and PM 2.5. PM 10 particles are smaller than 10 μm, and PM 2.5 are smaller than 2.5 μm, resulting from natural or human activities.
- the burning of fossil fuels (coal, petrol or diesel or gas) with the aim of producing electricity, or to be used in transport, etc.
- industrial emissions, where the energy source is wood or coal that emit pollutants such as nitrogen oxides, sulfur dioxide and carbon monoxide into the air. Industrial pollution has disastrous effects on human health, such as: irritation of the eyes, of the throat, diseases of the earth and possibly chronic diseases or cancer.
- vegetation fires increasingly represent a major cause of pollution, they can be natural or man-made; here the most suggestive example being the incentives caused intentionally in the Amazonian forest in order to obtain new agricultural areas
- agricultural activities that have a very important impact on the degradation of air quality over long periods of time. Fertilizers and pesticides are the main sources of air pollution around the areas where they are applied.
- nitrogen dioxide is a gaseous pollutant and represents an extremely important element in air pollution in industrial or urban areas. Nitrogen dioxide is produced by human activities through the use of vehicles, by fueling units or by heating with thermal power plants.
- ozone is a gas that has 3 O atoms in its composition. On the one hand, it has a beneficial role when it is found in the upper part of the atmosphere where it forms a barrier that absorbs cosmic radiation, but it has a toxic effect in the air we breathe.

2.2 Analysis of air pollution and its effects

In 2021, in response to the increasing quality and quantity of evidence on the impact of air pollution, the WHO updated the annual average air quality guideline according to the PM2.5 criterion and considered it to have a value of 5μg/m3, which represents clean air, because under this value is considered to have a very important impact on human health. This update halves the level of the previous values, established in 2005 and which was set at the value of 10µg/m3. In order to achieve these objectives, the United Nations has established a series of intermediate objectives that refer to the concentrations of pollutants in the air and which are categorized as intermediate steps.

In the continuation of the article, various studies and graphs related to air pollution are presented, such as:

- Air pollution levels by zone and country;
- The main causes of air pollution grouped on large areas of the Earth;
- Distribution of deaths caused by air pollution;
- The percentage of deaths from each disease attributed to outdoor air pollution with fine particles in 2019;
- The worldwide incidence of ischemic heart diseases caused by the inhalation of fine particles from the ambient air;
- The global fulfillment of targets regarding environmental standards regarding air pollution;
- The percentage of deaths by types of conditions caused by air pollution;
- The level of fulfillment of air quality standards in Romania

2.3 Industrial air pollution

2.3.1 A brief history of air pollution

Air pollution has been around in one form or another since at least the Roman Empire and the Han Dynasty, when human activity began releasing methane and other greenhouse gases into the atmosphere. In medieval London, the infamous smog was so noxious that King Edward II tried to ban the burning of certain types of coal – in 1272 – to no avail. Air pollution fast forwards to the "Industrial Revolution", when in 1872, 273 people died from bronchitis caused by air pollution. Today, the US Environmental Protection Agency (EPA), together with standards bodies in the European Union, China and other countries, conducts multiple and deep researches and develops technologies to help understand the causes of pollution and find remedies for air pollution. This research is conducted and synthesized every five years to ensure that current air pollution standards and regulations meet the needs of a growing global population [2].

2.3.2 Variation of pollutant gas emissions at European level

According to the latest studies from April 2022, at European level, industrial emissions of air pollutants that harm human health and the environment decreased between 2010 and 2020 in Europe [3]. Emissions of greenhouse gases (e.g. carbon dioxide (CO2) and sulfur oxides (SOx)) and other pollutants (e.g. nitrogen oxides (NOx), particulate matter (PM10) and heavy metals) decreased in significantly. Contrary to expectations based on these reductions in greenhouse gas emissions, the economic value generated by Europe during this period increased up to 2019, in line with the objective of the EU industrial strategy to support the competitiveness of European industry. According to the latest official data between 2010 and 2020, industrial emissions of SOx and PM10 fell by around 70% in the EU. Other emissions decreased to a lesser extent: heavy metals (Cd, Hg and Pb) by 56%, NOx by 41%, NMVOCs by 27% and CO2 by 24%. However, data from recent years is not yet secured and corrected by the reporting countries and may therefore vary slightly. Over the same period, the value that industry generated for the economy – measured by gross value added (GVA) – increased by 2019, indicating that European industry has become less emitting, with the ratio of emissions of atmospheric pollutants and the production of industrial goods that has decreased. The Covid-19 pandemic had different rates of impact on GVA and air emissions: while GVA decreased by 7% between 2019 and 2020, emissions of some pollutants (SOx, PM10 and heavy metals) decreased more in each year (over 10%) compared to others (nitrogen oxide emissions were almost stable between 2019 and 2020).

The decrease in industrial air pollutant emissions can be partly attributed to European regulations such as the EU Emissions Trading System and the Industrial Emissions Directive, improved energy efficiency and emission reduction technologies, and the relocation of various highly polluting and energy-intensive productions .

The following is a summary of the third chapter entitled "**INDUSTRIAL AIR FILTERING SYSTEMS. AIR FILTRATION IN BODY REPAIR SHOPS AND PAINTING SHOPS". In the first sub-chapter 3.1 "Air filters used for domestic and industrial purposes**", several types of classic air filters, which can be used in this field, are presented, as follows:

- filters for the penetration of dust, water, rain caused by wind and salt fog, which are used in the situation where it is desired to filter the air from the outside to the inside;

- fire-resistant filters, which can be cleaned and which offer a small pressure drop, with the ability to capture large amounts of dust from the air in applications in industrial premises;

- pleated air filters made of a layer of polyester, paper or cotton in pleats to increase the entire exchange surface;

- panel air filters are installed in HVAC systems to remove contaminants from the air flow;

- bag filters are filters used in HVAC applications to remove dust from the ambient air;

- activated carbon filters;

Since filters using activated carbon represent cutting-edge technology, some very important elements are presented below.

3.2 Air filtration using activated carbon

Currently, in the world, many of the air filtration systems, especially those used in the construction of the air filtration systems in the paint booths, use activated carbon filters.

Generally speaking, carbon air filters are the most commonly used filters for removing gases. They are designed to filter gases using a layer of activated carbon and are typically used to remove volatile organic compounds (VOCs). They can also be used for domestic purposes to remove odors from the air, such as the smell of tobacco smoke. As disadvantages, they cannot remove fine particles such as mold, dust or pollen from the air [2]. Activated carbon air filters remove pollutants from the air through a process known as adsorption. Important to note is that this process is totally different from the one called absorption. In absorption, the substance to be removed (say water) is absorbed into the structure of the absorbent (like a sponge), but does not become part of the absorbent at the molecular level. Therefore, when, for example, you absorb water with a sponge, the water does not chemically stick to the sponge. it just fills the volumes inside it. Thus, activated carbon filters are used to filter volatile organic compounds from the air. These are gaseous elements that most mechanical filters, such as HEPA filters, cannot remove. Practically, the gases released in the drying process of paint or cleaning substances can be removed from the air using the carbon filter and benzene and toluene, and some chlorinated compounds are among those that can be removed by this type of filters.

Since the application of the ultrasonic cavitation filtration system was carried out in a car body repair workshop, in the following sub-chapter, its characteristic elements are presented very briefly

3.3 Classic air filtration systems in painting booths

Paint booths represent work systems where air quality is very important. When talking about air quality in these systems, it must be taken into account that there are three subsystems here that work successively [3].

First of all, in order to fulfill its functional role, the air in the cabin must be of advanced purity, it must be free of particles for the painted surfaces to be perfect, without impurities. For this there must be an intake system through which the air is filtered [3].

The second system must provide compressed air for the gun with which the technological painting process is carried out. And this air, from a quality point of view, must also be filtered in order for the painted surfaces to be of high quality.

The third air filtration system refers to the exhaust into the atmosphere of the heavily polluted air resulting from the technological process of painting.

Thus, the filters used in the construction of the air filtration system in the paint booths are classified as follows (https://www.taffguard.com/our-filter-blog/paint-filtration):

- filters for the air replenishment unit
- intake filters
- exhaust filters.

The second part of the doctoral thesis is focused on the author's personal contributions both at the theoretical and at the practical, experimental level aimed at the realization of the air filtration system based on the phenomenon of acoustic cavitation. This part begins with chapter 5 entitled "**DIRECTIONS, MAIN OBJECTIVE AND RESEARCH-DEVELOPMENT METHODOLOGY OF AN INDUSTRIAL AIR FILTRATION SYSTEM BASED ON THE PHENOMENON OF ULTRASONIC CAVITATION**". It includes the following subchapters:

5.1. Research and development directions

To achieve the proposed objectives, we have established two main research directions that take into account the complexity of the piezoelectricity phenomenon that is the basis of the ultrasonic cavitation phenomenon that is used in the industrial air filtration process.

Regarding the development of the air filtration system, we followed the design of the tank in which the ultraacoustic cavitation takes place, as well as the industrial air filtration installation. We also followed the design of the system for measuring gas emissions that appear in the tinsmith workshop during the technological processes there.

5.2. The main objective of the research-development activity

5.2.1 The main objective of the research activity

The main objective of the research activity is divided into two main directions, both equally important. The first direction of research refers to the study of the phenomenon of piezoelectricity which is finally realized in the analytical calculation and in the modeling of the operation of the ultrasonic system formed by the piezoceramic elements, the amplifier and the ultrasonic concentrator. The modeling and simulation of the operation of the ultrasonic system was carried out using the finite element method implemented by the ANSYS software.

The second growth direction was realized in the sense of the study of the ultrasonic cavitation phenomenon, the one that leads to the formation of cavitation bubbles that are primed by the impurities coming from the industrial air that needs to be filtered.

From the point of view of technological research and development, the following was pursued and achieved:

- selection of the appropriate piezoceramic transducers resulting from their calculation and design stage;
- positioning them on the bottom of the tank where the phenomenon of ultrasonic cavitation occurs,
- dimensioning and construction of the tank for air filtration
- the design and realization of the system for measuring the emissions that take place within the technological processes that take place in a tin-painting workshop.

In chapter 6 entitled "**Theoretical and experimental research regarding the mathematical design of the ultrasonic system**" some introductory notions are presented at the beginning of it as follows:

6.1 Piezoelectricity

6.1.1 Introduction

Piezoelectricity represents a property of certain dielectric materials to change their geometric shape in the presence of an electric field or, on the contrary, to produce an electric charge when they are mechanically deformed by applying a concentrated force to them. There are a wide variety of materials that exhibit this phenomenon to some degree, including natural quartz crystals, semicrystalline polymer, polycrystalline piezoceramic, bone, and even wood. Piezoelectricity is produced due to the spontaneous separation of electrical charge in certain crystalline structures under appropriate conditions. This phenomenon, called spontaneous polarization, is caused by a displacement of the electron clouds relative to their individual atomic centers, that is, a displacement of the positive ions relative to the negative ions in their crystal cells. Such a situation produces an electric dipole.

Piezoceramic materials are used in a series of very important industrial and scientific fields that include elements of high intelligence and innovation. Thus, we can find such structures, in areas such as: industrial automation; military industry; high precision engineering and mechanics; aviation and space activities; automotive industry; advanced medicine; telecomunications; consumer goods industry

Piezoelectricity being the essential phenomenon on the basis of which the ultrasonic cavitation process is carried out, it is absolutely necessary to study the parameters on the basis of which it is produced and on the basis of which the ultrasonic system used in the design and realization of the air filter tank is designed. In general, the following notions are used in the analysis of piezoceramic materials: T = mechanical tension; S = mechanical strain; E = constant electric field (short-circuited electrodes); D = constant electrical displacement (electrodes in open circuit); For example, KT3 represents the dielectric constant measured between the polar electrodes of an unembedded piece of piezoceramic material. In a simplified form, the basic relationship connecting electrical and elastic properties can be represented as follows:

$$D = d\,T + \varepsilon^{T} E$$

$$S = s^{E}\,T + d\,E$$

These relationships apply only to small electrical signal amplitudes and small vibration amplitudes, the so-called small signal values. In this range, the relationships between the components of the elastic strain (S) or mechanical stresses (T) and the components of the electric field E or electric flux density D are linear.

Next, the relationships between the applied electric fields and the resulting responses depend on the piezoelectric properties of the ceramic, the geometry of the part and the direction of the electric excitation. Piezoceramic material properties vary with both strain and temperature. The piezoceramic material is primarily defined by the polarization directions.

$$T_1 = \tau_{11}\ ;\ T_2 = \tau_{22}\ ;\ T_3 = \tau_{33};\ T_4 = \tau_{23};\quad T_5 = \tau_{13};\ T_6=\tau_{12} \qquad (6.2)$$

Where T is the applied stress (N/m2).

A first element to characterize the phenomenon of piezoelectricity is the polarization vector. This is defined during the manufacture of the piezoceramic material by a high DC voltage applied between the electrodes and is represented by an arrow pointing from the positive to the negative electrode. This information is conveyed by drawing a dot or stripe on the surface of the electrode held at high voltage during the polarization process. Piezoelectric coefficients relate input parameters to output parameters, and a double subscript is used in their representation. The first index indicates the direction of the electric field E or dielectric D, and the second index refers to the direction of the mechanical stress T or strain S [5,9,10,11, 12,13, 35, 36,37].

The piezoelectric charge coefficient is a tensor of the 3rd order that can be expressed as a 3x6 matrix that correlates the displacement of the unit area of the electric charge (with short-circuited electrodes), associated with the application of mechanical stress, according to the relation:

$$D_i = d_{ij}T_j$$

The piezoelectric stress coefficient g, is represented by a 3 x 6 matrix and correlates the electric field, E developed, (with the electrodes in open circuit), with the mechanical stress T, according to the relation:

$$E_i = -g_{ij}\ T_j$$

Piezoelectric coefficients, used to relate input parameters to output parameters, are denoted with a double subscript. The piezoelectric deformation coefficients, d_{ij}, correlate the state of deformations with the applied electric field according to the relation:

$$S = d_{ij}\ E$$

The coupling coefficient, k, presents the ability of materials to transform electrical energy into mechanical energy [6,7,8]. Specifically, the square of the coupling coefficient is equal to the ratio of the mechanical energy provided at the output to the electrical energy input into the piezoceramic material. This coefficient is more relevant for the maximum working power of solid ceramic devices (with relatively equal dimensions on the three axes) than for elements with a length significantly longer than the other two dimensions, capable of bending, because a piezoceramic element of this shape stores some of the mechanical energy into the support and the metal core layer of the support. For bending elements kefective ~ ¾ k31.

The relative dielectric constant, K represents the ratio between the permittivity of the piezoceramic material and that of the void, ε0 (ε0 = 8.854x10-12 farad/meter). K3, represents the relative dielectric constant between the polarizing electrodes, determines the electrical capacity of the part as follows:

$$C = K_3\, e_0 A/T$$

Where A is the surface area of the electrode and T is the thickness of the ceramic layer or layers between the electrodes. Certain constants of piezoceramic materials are written with subscripts and at the top to specify the experimental context in which the parameter is measured.

Young's modulus, Y, represents the mechanical stress up to which the material behaves elastically and describes the stiffness of the material. The unit of measurement is [N/m2]. A material whose properties are presented in table 6.1 is used to make the piezoceramic transducer.

Table 6.1 Properties of the piezoceramic material used to make the piezoceramic transducer used in the experiments

property	symbol	Measuring units	Value
density	ρ	g/cm^3	7.75
Curie temperature	T_c	^0C	295
relative permittivity along the polarization direction	$\varepsilon_{33}^T/\ \varepsilon_0$		1015
the relative permittivity in the direction perpendicular to the polarization direction	$\varepsilon_{11}^T/\ \varepsilon_0$		1250
the dielectric loss factor	$tg\delta$	10^{-3}	5
Coupling factor	k_p		0.55
	k_t		0.44
	k_{31}		0.3

	k_{33}		0.62
	K_{15}		0.65
The piezoelectric load coefficient	d_{31}	10^{-12} C/N	-100
	d_{33}	10^{-12} C/N	219
	d_{15}	10^{-12} C/N	418
The piezoelectric coefficient of electric potential	g_{31}	10^{-3} Vm/N	-11.1
	g_{33}	10^{-3} Vm/N	24.4
Frequency coefficients	N_p	Hz m	2195
	N_1	Hz m	1590
	N_3	Hz m	1930
	N_t	Hz m	2035
The elastic compliance coefficienta	S_{11}^E	10^{-12} m^2/N	12.7
	S_{33}^E	10^{-12} m^2/N	14
Coefficient of elastic stiffness	C_{33}^D	10^{10} N/m^2	14.8
Mechanical quality factor	Q_m		400
The temperature coefficient ε^T_{33}	TK ε^T_{33}	10^{-3}/K	5
Relative permittivity	C_ε		-4
coupling factor	C_k		-2

6.2 Ultrasonic cavitation

Since the main phenomenon used in the ultrasonic filtration process is ultrasonic cavitation, a phenomenon that occurs when ultrasonic waves propagate through a liquid medium, a series of researches on ultrasonic cavitation have been carried out, some of them with applicability in the field of filtration , being presented next. These theoretical researches support the fact that the ultrasonic cavitation process is capable of producing chemical changes that support the ability to filter air through ultrasonic cavitation. In several scientific researches, it was found that liquids exposed to ultrasound emit radiation and undergo chemical decomposition [54]. The phenomena that occur during the sudden bursting of the cavitation bubbles generated by the acoustic expansion of the pre-existing gaseous nuclei lead to the production of maximum temperatures that vary from 3000 to 50000 K, depending on the ultrasonic system used. For example, chemical effects are compatible with temperatures in the lower part of the range, while discrete emissions from excited OH, C2 and CN molecules require temperatures above about 60000 K. The dynamics of cavitation bubble breakup is determined by the conservation of energy during the transformation external energy in the kinetic energy of the liquid shell, the heat content of the gases, the enthalpy of chemical reactions, the emitted radiation and the heat lost in the liquid. The explicit incorporation of chemical enthalpy changes into the bubble motion equation characterizes the complex and sometimes surprising effects associated with acoustic cavitation in liquids.

The theory related to the development of cavitation bubbles shows that sonochemistry and sonoluminescence are related and complementary manifestations of imbalance phenomena inexplicably linked to the rates and energies of chemical reactions. In conclusion, as can be seen, the chemical reactions are multiple, take place at very high temperatures and are capable of changing the chemical composition of the polluted air that is transferred through the tank where the ultrasonic cavitation process takes place.

Cleaning and filtering operations using ultrasonic energy in liquids are the result of the effects of the propagation of ultrasonic waves on the medium through which they propagate, the most important being: ultrasonic absorption and dispersion, ultrasonic cavitation and a series of effects of a mechanical, ultrasonic, chemical and biological nature. In his work [43], Kenneth says that an intense ultrasonic field propagating through a liquid causes cavitation bubbles, which by implosion generate very high temperatures, around 5500 0 C, thus forming a special environment in which chemical phenomena occur. The first chemist who recognized the special effects of the ultrasonic field propagating in a liquid was Alfred I. Loomis, who laid the foundations of sonochemistry. The chemical effect of ultrasound results from the physical process that creates, develops and then leads to the imposition of cavitation voids in which gases and vapors are found [44].

Figure 1 shows the four phases, filmed, of the appearance and implosion of a cavitation bubble [48].

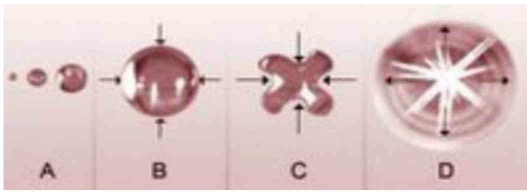


Fig 1 Formation and implosion of a cavitation bubble:
a – the formation of the cavitation bubble; b – expansion of the bubble;
c,d – implosion of the cavitation bubble
https://www.ultratecno.eu/technology/ultrasound-cavitation/

The formation of the cavitation bubble occurs as a result of a stretch-compression process with frequencies at the ultrasonic level, as can be presented in figure 6.6.

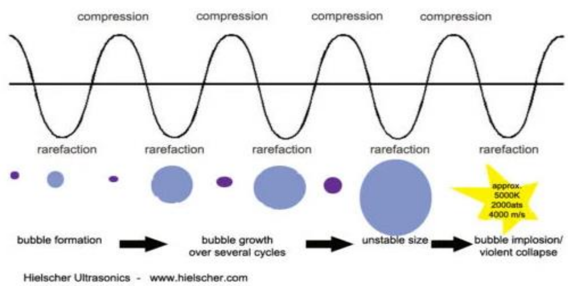


Fig. 2 The tensile-compression process with ultrasonic frequency that leads to the formation of the cavitation bubble https://www.ultratecno.eu/technology/ultrasound-cavitation/

In conclusion, it can be said that the ultrasonic field filtration process is the result of the appearance of the ultrasonic cavitation phenomenon and its acceleration due to the presence in the liquid medium of some cavitational germs, germs introduced together with the gaseous medium to be filtered and purified (all existing pollutants in the gaseous stream either in solid, liquid or gaseous state). This explains the very high percentage retention of some polluting gases for the environment (acetone, toluene, butyl acid, some hydrocarbons, etc.) because the phenomenon of ultrasonic cavitation accelerates the process of chemical dissolution of gases in water and makes possible the development of chemical reactions which would not be possible without the action of ultrasonic energy. In the industrial applications of ultrasound, several working frequencies are usually used, which are presented below.

One of the personal contributions of the doctoral thesis refers to the theoretical design, calculation and dimensioning of the ultrasonic system. This is presented in subsection 6.4.

6.4 Calculation and dimensioning of the ultrasonic system used to obtain the phenomenon of ultrasonic cavitation.

To calculate and size the ultrasonic system, according to [22,23], the initial data needed to solve the equations that describe the vibrational behavior of piezoceramic materials are first entered, namely:

- permittivity of the material ε_0=8.85·E-12 [F/m]

- the resonance frequency - f_0 = 2.5x104 Hz

- the resonance pulsation - ω_0=2πf_0=15.7 ·E4

- the minimum amplitude at the peak of the active part - ξ= 39·10-6 m
- input electrical power - Pin = 1500 W
- minimum acoustic intensity - Ia = 190 W/cm2
- acousto-mechanical performance – η = 0.75
- the electromechanical coupling factor – ζ = 0.65
- randamentul electroacustic- ηea = 0.98
- density ρ=7.6·10^3 [Kg/m3]
- Young modulus - Y=7.6·10^10 [N/m2]
- relative permittivity at 1 Hz -ε_rp=2600
- loss angle - δp = 0.6982 deg ; tg (δp) = 0.014
- the piezoelectric constant - k_p=665·E-12 [m/V]
- Curie temperature - "Θ" = 560.15 K

The reflector is made of a Ti5AlV titanium alloy with the following characteristics:

- Young modulus - Y=80.3 [N/mm2]
- density- ρ=4.43·E3 [Kg/m3]

Using the input data presented previously, the dimensions of the transducer composed of a passive element (the reflector) and an active element were calculated, assuming the determination of the following parameters:

- ultrasound propagation speed through components:

$$v_p = \sqrt{\frac{Y}{\rho_p}} = 3.25x10^3 \text{ m/s}$$

$$v_{Ti} = \sqrt{\frac{Y_{Ti}}{\rho_{Ti}} = }4.258 \text{ [m/s]}$$

$$v_{OL} = \sqrt{\frac{Y_{Ol}}{Q_{Ol}}} = 5.25 \times 10^3 \quad \text{m/s}$$

where: v_p is the ultrasound propagation speed in the piezoceramic element; v_{Ti}- is the ultrasound propagation speed in the piezoceramic element in the reflector, vOL - is the ultrasound propagation speed in the concentrator.

The wavelength of ultrasound :

$$\lambda_p = \frac{v_p}{f_0} = 938 \text{ mm} \quad =130 \text{ mm}$$

$$\lambda_{TI} = \frac{v_{pTi}}{f_0} = 121.66 = 170 \text{ mm}$$

$$v_{OL} = \sqrt{\frac{Y_{Ol}}{Q_{Ol}}} = 5.25 \times 10^3 \quad \text{m/s}$$

where: λ_p is the wavelength in the piezoceramic element; λ_{TI} - the wavelength in the reflector; λ_{Ol} - lthe wavelength in the concentrator.

The dimensions of the components according to the longitudinal direction of propagation of the ultrasonic vibrations in /4 are:

$$d_{Ol} = \frac{Ol}{4} = 52$$

$$d_p = \frac{p}{4 \cdot 2} = 16$$

$$d_{Ti} = \frac{Ti}{4} = 42.5$$

where d_{Ol} is the length of the concentrator; d_p – length of the piezoceramc elements; d_{Ti} – the length of the reflector.

- The radiation area of the active element must be correlated with the input power and the required acoustic intensity and is:

$$A_p = \frac{P_{in}}{I_{a} \cdot \eta_{ea}} = 1500/0.75x190 = 10.52 \text{ cm}^2$$
$$A_{Ti} = A_p = 1500/0.75x190 = 10.52 \text{ cm}^2$$

$$A_{Ol} = A_p = 1500/0.75x190 = 10.52 \text{ cm}^2$$

where A_p, A_{Ti}, A_{Ol} are the radiation areas of the three elements of the ultrasonic transducer.

- active element radius (for circular section), r_p:

$$r_p = \sqrt{\frac{A_p}{\pi}} = 18.3 \text{ mm}$$

- the electromagnetic transformation coefficient, n_p:

$$n_p = k_p \cdot Y_p \cdot \frac{A_p}{d} = 665\,E - 12 \cdot 63E9 \cdot \frac{1052}{16} = 2.75$$

- The acoustic impedances of the transducer elements:

$$Z_p = \rho_p \cdot v_p \cdot A_p = 7500 \cdot 3.25E3 \cdot 10.52E - 4 = 2.56E4 \text{ Kg/s}$$

$$Z_{OL} = \rho_{pOl} \cdot v_{Ol} \cdot A_{Ol} = 7800 \cdot 5.25E3 \cdot 10.52E - 4 = 4.3E4 \text{ Kg/s}$$

$$Z_{Ti} = \rho_{Ti} \cdot v_{Ti} \cdot A_{Ti} = 4430 \cdot 4.25E3 \cdot 10.52E - 4 = 1.98E4 \text{ Kg/s}$$

$where$, ρ_{pOl}, ρ_{Ti} are the densities of the piezoceramic material, of the concentrator and the reflector respectively; v_p, v_{Ol}, v_{Ti} – the elements of the piezoceramic transducer, of the concentrator and the reflector respectively; A_p, A_{Ol}, A_{Ti} – the areas of the three volumes.

- he effective electrical characteristics required for the production of acoustic power under mechanical resonance conditions are:

-electric voltage, U_p given by the relationship:

$$U_p = (\alpha_0 \cdot Z_p \cdot P_{in} \cdot \eta_{ea})^{1/2}/n_p\, \eta_{am} = 1.45 \cdot 10^3\ V;\ \alpha_0 = 0.85$$

-the electrical capacity of the active element, C_p given by the relationship:

$$Cp = \varepsilon_0 \cdot \varepsilon \cdot Ap/dp = 1.24\ nF$$

For the compact writing of the relations, the notations are made:

$$Z_1 = Z_p = 2.56 \cdot 10^4\ Kg/s$$

$$Z_2 = Z_p + Z_{Ti} = 4.54 \cdot 10^4\ Kg/s$$

$$\tau = 2\rho_p \cdot v_p \cdot A_{Ti} = 2 \cdot 7.6 \cdot 10^3 \cdot 3.25 \cdot 10^3 \cdot 10.52 \cdot 10^{-4} = 5.19 \cdot 10^{-4}\quad Kg/s$$

$$Z_3 = jZ_2 + \tau + \tau_p = 10^4(j \cdot 4.54 + 5.19 + 1.38)\quad Kg/s$$

$$Z_4 = Z_p + Z_{Ol} = 2.56 \cdot 10^4 + 4.3 \cdot 14^4 = 6.86 \cdot 10^4\quad Kg/s$$

$$Z_5 = jZ_4 + \tau_p = 10^4(j \cdot 6.86 + 1.38)$$

$$Z_6 = Z_p + Z_{Ol} = 2.986 \cdot 10^4\quad Kg/s$$

- ideal resonance acoustic power, P_{ai0}, given by the relationship:

$$P_{ai0} = \frac{\left(2\alpha_0 \cdot \rho_0 \cdot v_p \cdot A_{Ti} \cdot \eta_p^2 \cdot U_p^2\right)\frac{Z_4}{Z_4 - Z_1}\eta_{am}^2}{\tau^2} = 0.892 \cdot 10^3\ W = 1.35 \cdot 10^3\ W$$

- acoustic power at resonance with consideration of radiation losses:

$$P_{ai0} = \frac{\left(2\alpha_0 \cdot \rho_0 \cdot v_p \cdot A_{Ti} \cdot \eta_p^2 \cdot U_p^2\right) \frac{Z_4}{Z_4 - Z_1} \eta_{am}^2}{\tau + \tau_p{}^2} = 0.68 \cdot 10^3 \ W$$

- the volume and mass of the components:

$$V_p = A_p \cdot d_p = 10.52 \cdot 1.6 = 16.83 \ cm^2$$

$$m_p = V_p \cdot \rho_p = 16.83 \cdot 10^{-6} \cdot 7.6 \cdot 10^3 = 0.121 \ Kg$$

$$V_{Ti} = A_{Tip} \cdot d_{Ti} = 10.52 \cdot 4.25 = 4.71 \ cm^3$$

$$m_{Ti} = V_{Ti} \cdot \rho_{Ti} = 44.71 \cdot 10^{-6} \cdot 4500 = 0.201 \ Kg$$

$$V_{Ol} = A_{OL} \cdot d_{OL} = 10.52 \cdot 5.2 = 54.7 \ cm^3$$

$$m_{Ol} = V_{Ol} \cdot \rho_{Ol} = 54.7 \cdot 10^{-6} \cdot 7800 = 0.426 \ Kg$$

In which m_P, m_{Ti} m_{Ol} are the masses of the piezoceramic elements, of the reflector and the ultrasonic energy concentrator

- Frequency dependence of acoustic power:

$$P_{ac}(f) = \frac{P_{a0}}{1 + Q_m^2(f)\left(\frac{f}{f_0} - \frac{f_0}{f}\right)}$$

- The variation of the transducer impedance module with frequency is given by the relation:

$$R_p(f) = \frac{1}{cos(f) \cdot c_p \cdot tg(\delta_p)}$$

In which:

$$\omega(f) = 2\pi f$$

$$(f) = \frac{Z_p}{sin(\omega_f) \cdot \frac{dp}{v_p}}$$

$$\tau(f) = 2\rho_p \cdot v_p \frac{A_{Ti}}{cos\left(\omega_f \frac{dT_i}{v_{Ti}}\right)}$$

$$Z_m(f) = \frac{Z(f)}{n_p^2}$$

$$Z_{tm}(f) = |Z_t(f)|$$

$$Z_{tm}(f_0) = 2.98 \cdot 10^5 \, \Omega$$

$$C_s(f) = \frac{1}{\varpi(f) \cdot Z_m(f)}$$

- the effective electroacoustic efficiency of the transducer of the compound transducer is:

$$\eta_{e\ ar} = \frac{p_{ao}}{p_{in}} = 0.77$$

- the force developed by the active element:

$$F_p = k_p \cdot U_p. \frac{A_p \cdot Y_p \cdot \eta_{e\ ar}}{d_p} = 4.55\ N$$

- the actual mechanical energy is of the form:

$$W_m = \frac{1}{2}\left(F_p^2 \cdot C_m\right) = 3.014\ Ws$$

- the electrical energy consumed is calculated with the relationship

$$W_e = \frac{1}{2}\left(U_p^2 \cdot C_p\right) = 0.25\ \ Ws$$

Calculation elements for the ultrasonic energy concentrator:

- the length of the concentrator is calculated with the relation:

$$L = \frac{n \cdot c}{2 \cdot f_0}\sqrt{1 + \left[\frac{ln(n)}{\pi \cdot n}\right]} = 78\ mm$$

in which: f_0 = 25000 Hz; n = 1; N = 3.5;

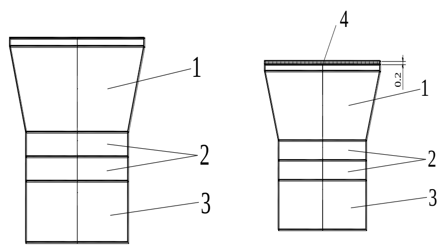
- nodal points x_{nod} is calculated with the relation:

$$X_{nod} = \frac{L}{n \cdot \pi} arc\ tg\ \left(\frac{ln\ ln\ N}{n \cdot \pi} + n \cdot \pi\right)$$

in which: n = 1; n' = 1,2,3

First nodal points $x_{nod\ 1}$ este: x_{nod} = 40.2 mm

As a result of the presented calculations, the composite piezoceramic transducer presentd in figure 3 was designed.



a. b.

Fig. 3 a - The piezoceramic transducer used to obtain the ultrasonic cavity phenomenon:
a. – constructive dimensions; b. – the constituent elements 1. – the ultrasonic amplifier; 2 – piezoceramic elements; 3 – ultrasonic reflector; 4 – adhesive layer

Knowing the vibration mode of the ultrasonic system is particularly important because in the experiments it is not possible to go through all the vibration frequencies in the ultrasonic field, between 18000...100000 Hz. Therefore, finding useful working frequencies helps to operate and optimize the cavitation process and provides a very clear picture of what is happening in the studied frequency range. After designing the compound piezoceramic transducer, one of the important issues is attaching it to the bottom of the ultrasonic tank where the ultrasonic cavitation occurs. Its bonding is extremely important because a very rigid fixation could cause the link to crack during vibrations, while a very flexible adhesion could cause a strong damping of the oscillations and as a result they will not be transmitted inside the tub. For this, I chose a silicone-based adhesive that is deposited between the transducer and the bottom of the tank, with a relative thickness of approximately 0.2 mm. Figure 3b shows the scheme of the system thus realized. The mechanical properties of the adhesive layer will be presented in the stage of modeling and simulation of vibration modes. For the efficient production of the ultrasonic cavitation phenomenon, 10 piezoceramic transducers were placed in the lower part of the tank, whose placement scheme is shown in figure 4.

6.6 Designing the functional scheme of the industrial air filtration system using the phenomenon of ultrasonic cavitation

As both a practical and a theoretical contribution, I designed the functional scheme of the air filtration system by ultrasonic cavitation is shown in figure 5. Analyzing the component elements in this scheme, it can be said that it is formed by flexible tube 1 introduced in the liquid and introduces the air which must be filtered through the phenomenon of ultrasonic cavitation. It is forced in through the suction fan 4 which is fed from inside the paint booth through the piping.
The control element 6 of the suction pump 7, provided inside with a fan 8, is fixed on the cover 3. The suction pump 7 takes the purified air and sends it into the atmosphere. In order to measure the quality of the filtered air, a hole is made inside the tubing of this pump where the measuring probe 10 will be inserted, which is connected to the system for measuring the quality of the filtered air 9. Also on the cover 3 the electronic engine power system will be mounted 13, of the suction fan 4.

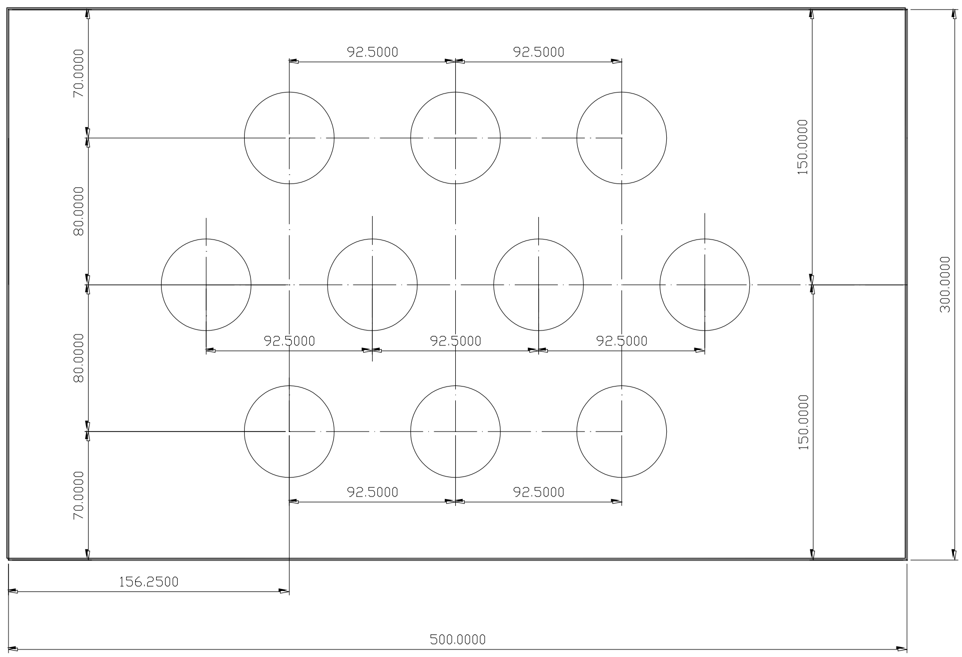


Fig. 4 Diagram of the placement of the piezoceramic transducers on the bottom of the tank

In chapter 7 entitled "**MATHEMATICAL MODELING OF THE PROCESSES THAT TAKE PLACE AS A FOLLOWING OF THE ACOUSTIC CAVITATION PHENOMENON**" a mathematical model based on the theory of finite elements is presented. This chapter is considered as personal contributions in the mathematical field for determining the optimal modes of vibration and for the theoretical determination of the optimal thickness of the adhesive layer required to bond the transducers to the bottom surface of the tank. It consists of the following subchapters:

7.1 Mathematical modeling of the ultrasonic system and determination of optimal vibration modes

Mathematical modeling using the finite element method is currently a working method that can be found in many scientific fields, including medicine. Engineering has benefited from the contribution of this method for about 40 years, being used mainly due to its results that approach the real behavior of the systems with a precision of about 90%. In order to obtain results as close as possible to reality, entering input data is extremely important. In this sense, the steps taken to solve the proposed problem will be presented below

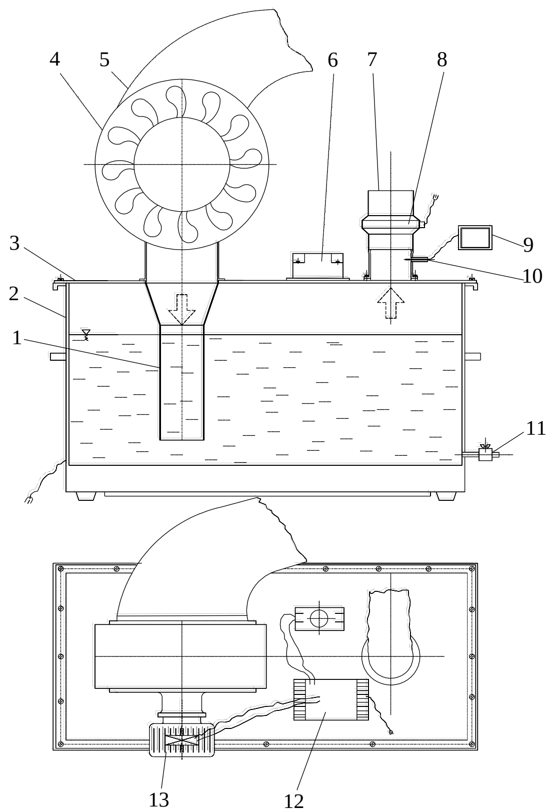


Fig. 5 Functional diagram of the industrial air filtration system using the phenomenon of ultrasonic cavitation

1 – internal air inlet piping that must be filtered; 2- tank with liquid for producing the phenomenon of ultrasonic cavitation; 3 – liquid; 4 – industrial air suction fan; 5 – industrial air inlet piping with impurities and noxes; 6 – electronic fan speed regulation system; 7 – piping system for removing the filtered air into the atmosphere; 8 – fan for extracting the filtered air; 9 – filter air chemical composition determination system; 10 - probe for determining the chemical composition of the filtered air; 11 - water discharge valve; 12 – electronic fan motor power supply system; 13 – fan motor

This problem consists in determining the vibration modes and optimal vibration frequencies, useful in obtaining the cavitation phenomenon.

7.1.1 Realization of the theoretical, virtual model of the ultrasonic system

In the first stepe, very important, the type of discretization element used in solving the proposed problem is chosen. In the studied case, two discretization elements are used since the analysis is of modal type and the vibration modes come from the piezoceramic elements. The phenomenon of piezoelectricity is analyzed and studied by using an element SOLID98 (ANSYS software). It transforms electrical energy into mechanical energy being a Coupled Field type element.

To create the proposed model, four types of material are used as follows:

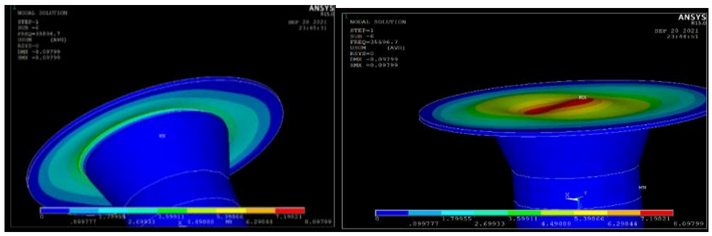
1. steel – for modeling the lower part of the tub;
2. aluminum – for modeling the reflector and the concentrator of the ultrasonic system;
3. piezoceramic material – for piezoceramic disks;

the silicone adhesive for modeling the adhesive layer that secures the transducer to the bottom of the tub.

7.1.2 Modal Analysis of the transducer system – cavitation tank. Determination of eigenvibration modes and vibration frequencies

After performing a "Modal" analysis, the program provides several modes of vibration. Modal analysis provides the free, eigenmodes of vibration of a mechanical, ultrasonic, or other vibrating structure. These free vibrational modes are unique to each system and occur at software-determined frequencies. This analysis helps to tune the ultrasonic systems to the optimal vibration frequencies that are also achieved with minimal energy consumption. This avoids sweeping a very large range of frequencies in the ultrasonic range starting from 18 KHz up to approximately 100 KHz. Ultrasonic systems can operate at several frequencies, but the optimal ones can be found by performing modal analysis, in this case provided by the Ansys software. Among the calculated frequencies, some of them, especially the first ones, are very possible to achieve, while the following ones are less so.

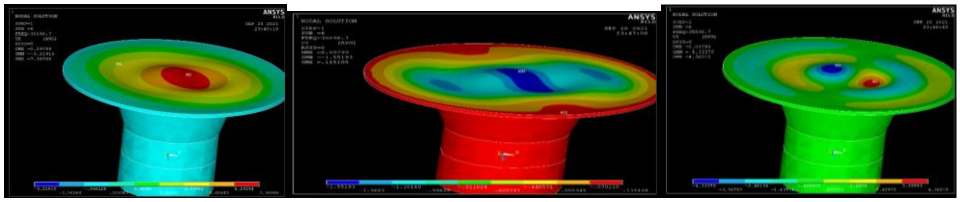
Next, two possible vibration modes are presented, very close to the real oscillation mode and which occur at frequencies close to the working frequency offered by the manufacturer of the piezoceramic elements, namely f = 35000 Hz. Figure 6 shows the vibration mode at the frequency f = 35596 Hz as the sum of the deformations. As can be seen, in the center of the energy concentrator, oscillations occur mainly on the OZ axis, but which also show displacements on the other two axes. From the analysis of the image, the behavior of an extremely important area such as the adhesion of the transducer to the surface of the tank can be observed. Here, the silicone adhesive undergoes small deformations, exactly in the range where they can transmit oscillations from the transducer to the tank.



a. b.

Fig. 6 Presentation of the sum of deformations at the frequency f = 35596 Hz; a – the lower part of the tank; b – the upper part of the tank that deforms due to the production of vibrations in the ultrasonic field

One of the most important advantages of using mathematical models based on finite element theory refers to the presentation of results that are extremely difficult to obtain through measurements and therefore to understand. Thus it becomes possible to know the processes in detail and with great accuracy. Thus, for a closer understanding of the production of vibrations in the ultrasonic field, figure 7 a shows the oscillations along the OX axis in which the maximum amplitude occurs in its positive direction, in the negative direction no vibrations are produced. For the OY axis, the oscillations shown in figure 7.5 b show maximum displacements in the negative direction of the OY axis. The most important observations can be found in figure 7.5 c, which shows the oscillations along the OZ axis, which essentially contributes to the transmission of vibrations in the liquid medium in the tank. As can be seen from the image analysis. Along the OZ axis, oscillations generating longitudinal waves are produced alternately in the respective positive direction of the OZ axis. In this case, at this frequency there were two points generating oscillations, close to each other and close to the longitudinal axis of the ultrasonic system.



a. b. c.

Fig. 7 Presentation of the oscillations of the ultrasonic system at the frequency f = 35596 Hz related to: a - OX axis; b - axis OY; c - axis OZ

The program also provides a second working frequency at which the ultrasonic system can be operated, namely at f = 31223 Hz. Figure 8 shows the image representing the sum of the deformations. As can be seen, in the center of the ultrasonic system there is a source of oscillations, the ultrasonic transducer concentrating the ultrasonic energy here. The area shown in red will generate the longitudinal oscillations that will produce the phenomenon of ultrasonic cavitation used in air filtration.

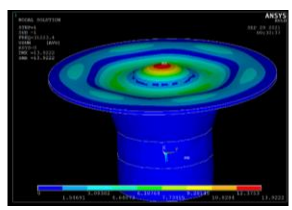
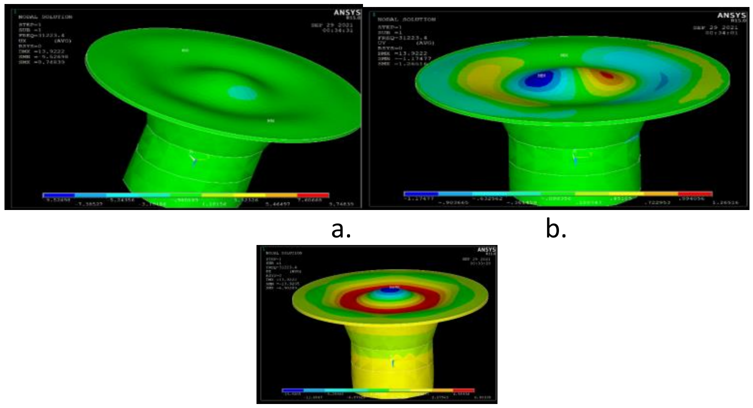


Fig. 8 The presentation of ultrasonic oscillations at the frequency f = 31223 Hz as the sum of the deformations of the studied system.

For a better understanding of the processes carried out at this frequency, figure 9 a shows the oscillations along the OX axis. For this case, it can be observed that their value is close to zero. The decomposition of the vibrational motion along the OY axis is shown in figure 9 b. Relative to this axis, one can observe an area with displacement in the positive direction of the OY axis (red color) and an area with displacement in the negative direction of this axis, the shape of the central area generators of oscillations remaining the same.



a. b.

c.

Fig. 9 Presentation of the operation of the vibratory system at the frequency f = 31223 Hz; a - vibrations along the OX axis; b = vibrations along the OY axis; c - vibrations along the OZ axis

The most representative image is presented in figure 9 c where it can be observed how the central area in the shape of an "egg" vibrates along the axis OZ, perpendicular to the bottom of the tank generating trains of impulses that propagate in the liquid inside the tank. All the energy of the transducer is thus concentrated almost in one point which makes the efficiency of the vibratory system high at this frequency. Since the finite element method is a mathematical model that provides several results, in this case several vibration modes corresponding to several frequencies, it is very important to analyze the vibration modes that may occur in reality. In this sense, for example, figure 10 presents a mode of vibration at the frequency f = 19091 Hz, but which produces discontinuity at the level of the transducer's fixation on the surface of the tub. So this vibration frequency cannot be used for the optimal operation of the air filtration system based on the phenomenon of ultrasonic cavitation.

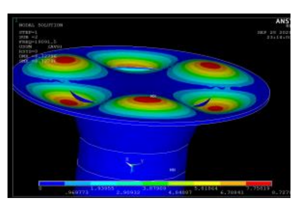


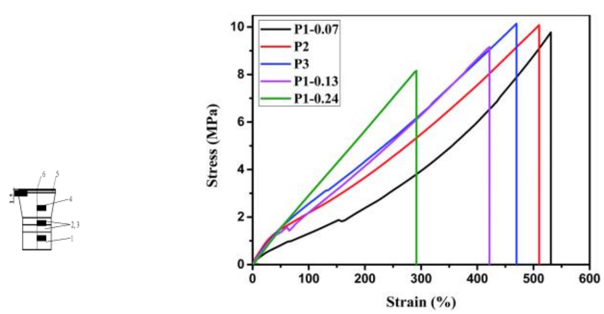
Fig. 10 The vibration frequency f = 19091 Hz and the corresponding vibration mode that cannot be used in the operation of the ultrasonic vibrator system

7.2 Mathematical modeling of the optimal energy transfer between the ultrasonic system and the cavitation tank. Determination of the thickness of the adhesive layer used to fix the ultrasonic transducer on the bottom of the cavitation tank

7.2.1 Defining the theoretical model of the ultrasonic system attached to the lower part of the tank by the silicone adhesive

The operation of the ultrasonic system at the frequencies at which there is an optimal transfer of energy between it and the cavitation tank is particularly important for the entire system to provide an optimal performance of the air filtration process.

One of the problems that arose during the construction of the filter system was that of fixing the transducer to the bottom of the tank by silicone glue. Since a rigid fixation is not possible, the only solution is to use an elastic silicone type material. It has the advantage that it can work up to high temperatures and is chemically stable. However, silicone bonding presented a very important problem because depending on the thickness of the adhesive layer, the phenomenon of transmission of vibrations from the transducer can be totally attenuated or, in a favorable situation, it can be amplified.



a. b.

Fig. 11 Transductorul ultrasonic folosit pentru obinerea fenomenului de cavitatie ultrasonica:

a. - elemente componente 1. -reflector ultrasonic; 2.3 - piezoceramic elements; 4 - amplificator ultrasonic; 5- cylindrical element; 6 - strat adhesive silicone; b mechanical properties of silicone adhesive according to Linglong Feng, Shusheng Lia and Shengyu Feng [1,2]

Knowing the thickness of this bonding layer was determined by finite element modeling. For this, the modeling started from the geometric shape of the transducer shown in figure 7.2, following which the silicone layer shown in figure 11 a was deposited. The mechanical properties of the silicone adhesive used are shown in figure 11 b. The mechanical properties of of the adhesive layer (silicone rubber) will be presented in the stage of modeling and simulation of vibration modes. The silicone rubber used to bond the ultrasonic system to the bottom of the tank is one of the most promising materials due to its unique properties, including superior temperature and chemical resistance, weather resistance, aging resistance, electrical insulation and biocompatibility. In general, the modulus of elasticity of silicone rubber is low, and the appearance of mechanical stress in silicone rubber immediately causes relatively large deformations, limiting its application to a certain extent, especially in dynamic circumstances.

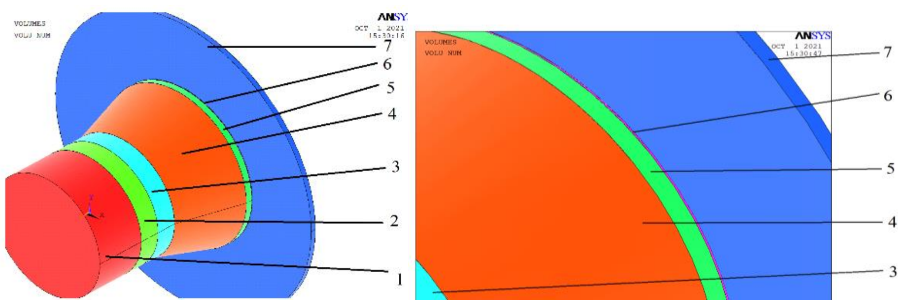


Fig. 12 a. - Presentation of the ultrasonic system used to produce the phenomenon of ultrasonic cavitation:
1 – ultrasonic reflector; 2,3 - disc-type piezoceramic elements; 4 - cone-shaped amplifier; 5 - connecting cylinder; 6 - fixing silicone adhesive; 7 - the bottom of the ultrasonic cavitation tank. b. - enlarged image of the joining area between the ultrasonic transducer and the bottom of the cavitation tank

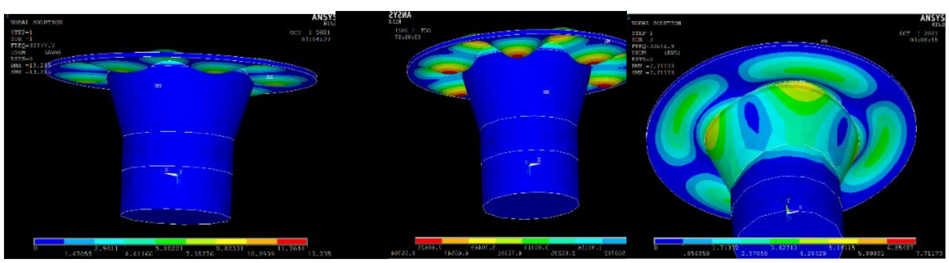
The modulus of elasticity of silicone rubber can be improved by adding additional materials to the classic rubber-based adhesive formula. The mechanical properties of silicone rubber were obtained from a universal testing machine WDW-5 (KeXin Testing Machine Co., Ltd) [1,2]. Figure 12 shows the model of the ultrasonic system consisting of: two piezoceramic elements; reflector; amplifier, fixing silicone adhesive; the bottom of the cavitation tank.

To determine the optimal thickness of the elastic silicone-based adhesive layer, three situations were considered where the thickness of this layer (position

6) is h1 = 0.1 mm, h2 = 1 mm and h3 = 1.5 mm. For each of these cases, a modal analysis was performed with the help of which the transfer of oscillations from the ultrasonic transducer to the metal surface of the bottom of the tank where the ultrasonic cavitation process takes place is studied. The study of the type and shape of the oscillations related to the surface of the lower part of the tank will allow choosing the optimal thickness of the elastic silicone adhesive layer [4,5,6].

7.2.2.1 Adhesive layer thickness h1 = 0.1 mm

The first case studied refers to a thickness of the silicone adhesive layer (position 6) h1 = 0.1 mm. Figure 13 presents (according to the modal analysis) vibration modes at frequencies f = 30377 Hz, f = 30490 and f = 30616 Hz respectively. A careful analysis of the vibrations in the area of the silicon layer shows that the amplitude of the vibrations causes its damage, which can no longer fulfill the role of an element of transmission of oscillations from the piezoceramic transducer to the bottom of the tank.

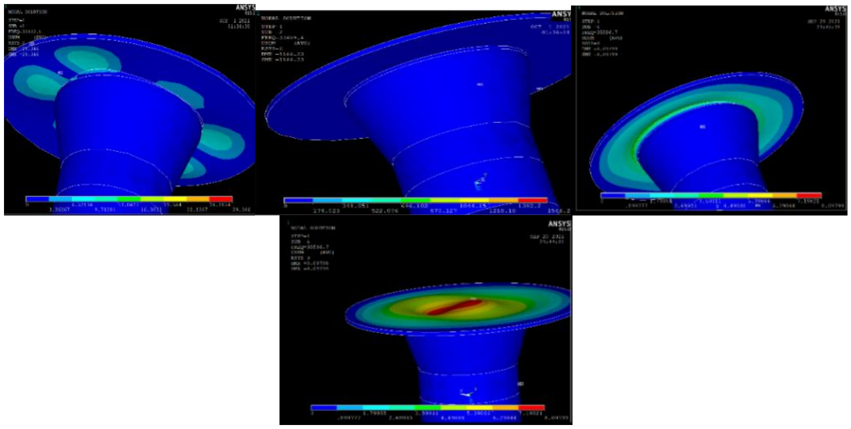


a. b. c.

Fig 13. Vibration modes in the case of a thickness h = 0.1 mm of the silicone adhesive a. - f = 30377 Hz; b. - f = 30490 Hz; c. - f = 30616 Hz.

7.2.2.2. Adhesive layer thickness h1 = 1 mm

In the second case studied, the natural vibration frequencies f = 30822 Hz, f = 33409 Hz were obtained (Fig. 14).



b. b. c. d.

Fig. 14 Vibration modes in the case of the silicone adhesive layer h = 1 mm; a. - f = 30822 Hz; b. - f = 33409 Hz; c, d - Vibration modes in case of silicone adhesive layer h = 1.5 mm f = 35596 Hz.

From the analysis of each image, it can be seen how the silicone layer is no longer destroyed and fulfills, at the limit, the role of a coupling element between the transducer and the bottom of the tank where the ultrasonic cavitation process takes place.

7.2.3.3 Adhesive layer thickness h1 = 1.5 mm

The third case studied refers to the realization of a coupling between the piezoceramic transducer and the tank by using a layer of silicone adhesive with a thickness of 1.5 mm. In this case, the modal analysis led to the calculation of a useful vibration frequency at f = 35596 Hz (Fig. 4). As can be seen from figure 5.12, the adhesive layer with a thickness of h = 1.5 mm maintains its integrity and optimally achieves a transfer of oscillations. At its core, the transducer produces vibrations that are the source of producing ultrasonic cavitation bubbles used in industrial air filtration.

In order to validate the functioning of the air filtration system through the ultrasonic cavitation process, in chapter 8 entitled "**EXPERIMENTAL RESEARCH ON AIR DEPOLLUATION THROUGH ULTRASONIC CAVITATION**" the measurements regarding the quality of the filtered air were presented. They are presented in several subchapters:

8.1 The technological parameters that define the behavior of the filtration system based on ultrasonic cavitation

To achieve air filtration through the phenomenon of ultrasonic cavitation, the designed and built installation requires two devices that:

- changes the pressure and air flow when it enters the filter system;
- it helps to extract the filtered air that is in the space between the free surface of the water and the lid of the filter tank, where it is found after the cleaning process.

8.1.1 Changing the pressure of the air to be filtered at the entrance to the water tank

In order to introduce the polluted air into the tank with water, it is necessary to produce an increase in air pressure because only in this way can it overcome the pressure barrier that occurs when it must be introduced into the tank with water where it is filtered. Required pressure and air flow, so at the same time also the flow of polluting substances represent unknown elements in the realization of experiences.

If the air pressure at the entrance to the tank is too low, it cannot form a mixture with the air in the tank and the ultrasonic cavitation phenomenon in which the cavitation germs are represented by the polluting particles cannot take place. The process of ultrasonic cavitation occurs anyway, but not in the sense of filtering polluted industrial air.

In the situation where the air pressure is too high inside the tub, non-laminar flows and turbulences can occur, which in no case have a favorable role in producing the cavitation phenomenon.

Therefore, establishing an optimal pressure of the air that you need to filter represents a very important requirement of the research that must be undertaken in this regard. Air pressure will be one of the variables in the future optimization equation of the ultrasonic cavitation filtration process.

Increasing the pressure and flow of air to be filtered and introduced into the tank is done with the help of a Casals type variable speed pump which is shown in figure 15 [1]. The fan is designed to transport air containing dust or impurities. It is a centrifugal, medium pressure fan with direct drive. The rotor has straight, backward curved, profiled, welded, sheet steel blades, dynamically balanced according to ISO 1940. This balancing is particularly important. Although the vibrations of the acoustic system are in the ultrasonic range ($f \leq 20000$ HZ), it is not right to have overlaps with the vibrations of other elements that work within the filter system. The casing is made of welded sheet metal and the electric motor is single-phase 230 V at 50 Hz, with capacitor. The motors are manufactured in accordance with IEC 60072 and IEC 60034 standards and have received the CE mark. Another very important characteristic, very necessary since the filtration system works in a humid environment, is the insulation class F, with the degree of protection IP 55. The air flow is 10.3 m3 per hour, very sufficient for the application made in this case.

8.1.1 Changing the pressure of the air to be filtered at the entrance to the water tank

In order to introduce the polluted air into the tank with water, it is necessary to produce an increase in air pressure because only in this way can it overcome the pressure barrier that occurs when it must be introduced into the tank with water where it is filtered. Required pressure and air flow, so at the same time also the flow of polluting substances represent unknown elements in the realization of experiences.

If the air pressure at the entrance to the tank is too low, it cannot form a mixture with the air in the tank and the ultrasonic cavitation phenomenon in which the cavitation germs are represented by the polluting particles cannot take place. The process of ultrasonic cavitation occurs anyway, but not in the sense of filtering polluted industrial air. In the situation where the air pressure is too high inside the tub, non-laminar flows and turbulences can occur, which in no case have a favorable role in producing the cavitation phenomenon.

Therefore, establishing an optimal pressure of the air that you need to filter represents a very important requirement of the research that must be undertaken in this regard. Air pressure will be one of the variables in the future optimization equation of the ultrasonic cavitation filtration process. Increasing the pressure and flow of air to be filtered and introduced into the tank is done with the help of a Casals type variable speed pump which is shown in figure 15 [1]. The fan is designed to transport air containing dust or impurities. It is a centrifugal, medium pressure fan with direct drive. The rotor has straight, backward curved, profiled, welded, sheet steel blades, dynamically balanced according to ISO 1940. This balancing is particularly important. Although the vibrations of the acoustic system are in the ultrasonic range ($f \leq 20000$ HZ), it is not right to have overlaps with the vibrations of other elements that work within the filter system. The casing is made of welded sheet metal and the electric motor is single-phase 230 V at 50 Hz, with capacitor. The motors are manufactured in accordance with IEC 60072 and IEC 60034 standards and have received the CE mark. Another very important characteristic, very necessary since the filtration system works in a humid environment, is the insulation class F, with the degree of protection IP 55. The air flow is 10.3 m3 per hour, very sufficient for the application made in this case.

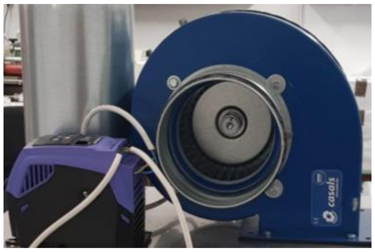


Fig. 15 Casals-type air pump used for pressurized introduction of polluted air into the filter tank

8.1.2 The variation of the air flow that must be filtered in order to be introduced into the tank

The flow of air to be filtered represents a second necessary variable in the equation for determining the quality of air filtered by ultrasonic cavitation. If the value of this parameter is very small, the efficiency of the filtering operation is low and this method would not find applicability. On the other hand, if the air flow, respective of polluting particles, is too high, the number of cavity bubbles may not be high enough for the filtration process to take place in efficient conditions. In this sense, this parameter must be adjusted so that one can speak of an efficient filtration process and the air flow is introduced into the equation for optimizing the quality of air filtered by this method.

8.1.3 Modifying and optimizing the flow of filtered air to be removed from the surface of the water tank

The third parameter involved in the optimization of the filtration process is the creation of a "depression" that occurs in the volume between the surface of the water in the filter tank and its cover. As the industrial air filtration process is supposed to take place, it is subjected to the filtration process by the appearance of cavitation bubbles that germinate the polluting particles that are introduced inside the water tank. After filtering, the cleaned air reaches the surface of the water in the tub, accumulating between it and the lid of the tub. In order for this accumulation of air not to increase the pressure on the surface of the water and thus to complicate the process of filtering and removing the filtered air, it is necessary that it be sucked in by means of a fan and sent outside, into the atmosphere. This extraction of the filtered air is carried out with the help of a fan which is presented in figure 16 [2].

Fig. 16 The fan for extracting the filtered air from the surface of the liquid in the water tank

8.2 Assembling and mounting the filter installation in the tin-painting workshop for measuring the quality of dissolved air through the phenomenon of ultrasonic cavitation

In the first stage of experimental research, the filtration installation was assembled separately, where its operation was checked from the point of view of each individual element that constitutes the ensemble of the filtration system.

First of all, the operation of the tub, namely the transducer system that forms the network of 10 ultrasonic transducers that will produce the ultrasonic oscillations inside the volume of water that constitutes the filtering element of the polluted industrial air, was checked.

Once the operation of the ultrasonic transducers placed on the bottom of the tank was checked, it was filled with water, after which the cover positioned on the top of the tank was mounted. The lid was secured by a series of screws positioned on the rim of the tub.

The cover mounted and fixed in this way is provided with two holes necessary for the installation of the fan necessary to extract the air that reaches the surface of the water volume and the turbo blower necessary to introduce pressurized air inside the water volume. The polluted air, which must be filtered, reaches the water volume of the tub through the inside of a plastic tube that is fixed on the air pump 4 (turbo blower) as shown in the principle diagram.

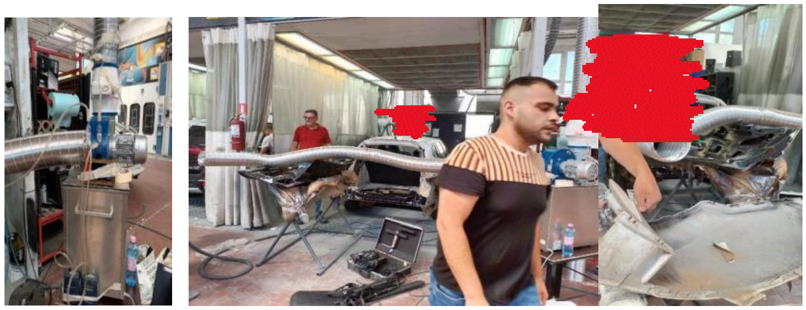
The subassembly consisting of the air intake tube and the air pump is mounted on the cover fixed in this way. To exhaust the depolluted air, also at this stage the air extraction fan marked with 8 in figure 5 is fixed.

Figure 17 a and b shows an overview of the filtration system based on the ultrasonic cavitation phenomenon. This image corresponds to the assembly stage of all the elements of the filter system.

a. b.

Fig. 17 Realization of the assembly of the industrial air filtration system based on the phenomenon of ultrasonic cavitation: a - frontal view; b - side view

The filter system based on the acoustic cavity thus made was installed in the paint shop of a specialized automotive repairing shop. Figure 18 shows the images during the installation and of the air quality measurements. As can be seen, in figure 18 a, the filter installation is shown which is connected through the piping on the left side to the areas where, in the work station, grinding, a high level of pollution occurs. The vertical piping is connected to the fan that extracts the filtered air which is then sent outside the tin-painting workshop. In figure 18 b, the air intake piping placed in the filtration area is shown.



a. b. c.

Fig. 18 Installation of the industrial air filtration system inside a painting workshop:
a. - the positioning of the filtration system in order to carry out the tests; b. - deploying the nox capture piping; c. - the positioning of the fumes collection pipe in the working area

To measure the quality of the filtered air, figure 19 presents the hole made for inserting the sensor to capture the air that will be analyzed at the exit from the filtration system. This hole was executed at approximately 200 mm to be in accordance with the standards.

Fig. 19 Execution of the air quality measurement point in the tubing from the filtered air outlet

9.3 Air quality measurement in a tinsmith workshop paint shop

Air quality measurement is the most important step in demonstrating the efficiency of the air filtration system using the phenomenon of ultrasonic cavitation. As can be seen below, this system comes and eliminates an important part of the disadvantages of using classic air filtration systems that use mechanical filters. As presented in Chapter 3, the classic air filtration system uses filters that present a number of important disadvantages such as:

- they have a relatively low operating time of about 100 hours;
- their replacement is cumbersome and involves an activity in which human operators are subjected, by handling the clogged filters, to exposure to the inhalation of particles very harmful to human health;
- the activity of replacing stained filters is time-consuming, which leads to a decrease in work yields in the paint shop;
- mechanical filters are relatively expensive and changing them at short time intervals, over long periods of time, will lead to significant costs incurred by the company.
- many of the types of filters used to exhaust polluted air require temperature or humidity requirements that often, due to operating conditions, cannot be met.
- the activity of permanent supply of filters is also an activity that requires time and human resources.
- already used black filters represent waste whose recycling is particularly difficult and leads to environmental pollution in the very long term.

By using the ultrasonic air filtration system through the cavitation phenomenon, all these disadvantages are eliminated. The initial investment, which, although higher, will amortize relatively quickly over time and the use of this system proves to be a "green technology" for a very long period of time.

In order to determine the effectiveness of the air filtration system through the system that uses ultrasonic cavitation, a series of measurements were made that will be described next.

9.3.1 Type of tests performed

The measurements made at SC TOP Lac targeted several series of parameters regarding the environment and the quality of the surrounding environment.

In order to determine the water quality, a series of measurements were made as follows :

- pH;
- suspended matter;
- chemical oxygen consumption - CCOCr;
- biochemical oxygen consumption-CB05,
- solvent extractable substances;

- anionic surfactant detergents.

When measuring contaminants these are expressed as milligrams per cubic meter (mg/m3) for particles and parts per million (ppm) for gases. For example, the maximum workplace exposure limit for total dust (inhalable) is 10 mg/m3 over a period of 8 hours. In order to have an indicative value of expressing the units of measure in which the measured values are expressed, we can say that:

- milligram per cubic meter (mg/m3) is about the same as a teaspoon of dust spread over the surface of a football field at a height of one meter.
- parts per million (ppm) is about the same as the contents of a party balloon compared to the volume of air inside 50 three-bedroom houses.

9.3.1.1 Sample collection and preservation method

The sampling method was done according to SR EN ISO5667-1:2007, SR EN ISO 5667-1:2007/AC:2007, SR EN ISO 5667-3:2018, SR ISO 5667-10:1994. The method of preservation of the samples was by cold storage.

9.3.1.2 The equipment used to make the measurements

The following equipment was used to perform the measurements:

- Multiparameter WTW;
- Caloris Group type EC25 oven, Binder FD 115 oven, CINTRA 6 spectrophotometer, Mettler Toledo analytical balance (with five decimal places)

9.4 Results of physical-chemical analyses

The results of the physical-chemical analyzes from the premises R1 SC TOP LAC Service COTROCENI SRL Bucharest, B-dul Timișoara, no. 6-8, Section 6 (Tab. 2). These values were included in Test Report no. 3043.

Before starting the determinations for volatile organic compounds and suspended particles, a series of measurements were carried out that are necessary for the emission assessment activity. According to table 9.5, the following were measured:

- Atmospheric Ph;
- Matter in suspension;
- CCOCr;
- CBO5;
- Solvent extractable substances;
- Anionic surface detergents.

The values of these determinations are presented in table 9.5.
At the same time, the uncertainties of the determination methods and the standards that were based on them are also presented.

Tab. 2 The results of the physical-chemical analyzes in the premises of R1 SC TOP LAC Service COTROCENI SRL Bucharest

No.	Analised indicator	UM	sample symbol / Determined values	Extended Relative Uncertainty, Method (k=2), %	Test method
			2887		
1	pH	Unit pH	7,7 (la 20.4^0 C)	± 2	SR EN ISO 10523:2012
2	Suspended matter	mg/l	88	± 15	SR EN 872:2005
3	CCOCr	mgO_2/l	87,58	± 15	SR ISO 6060:96
4	CBO_5	mgO_2/l	34	± 26	SR EN ISO 5815-1:2020
5	Solvent extractables substances	mg/l	<20	± 15	SR7587:1996
6	anionic surface detergents	mg/l	3.14	± 20	SR EN 903 :2003

9.4.1 Air quality measurements in the paint shop

As part of this series of analyses, measurements were made regarding:
- Temperature;
- Air speed;
- Humidity;
- Pressure;
- Volumetric flows.

9.4.1.1 The methods applied in order to make the measurements

The following methods were used to perform the measurements: PI-(v1,r1), SR EN 14790:2017; ISO 10780:1994, SR EN 15259:2008, SR EN ISO 16911-1:2013, SR ISO 14164:2008, ISO 10780:1994, STAS 8421-87 – automatic methods.

9.4.1.2 Used equipment

For the second series of measurements, a German-made TESTO 350 XL automatic analyzer equipped with temperature probe, Pitot tube, anemometer was used. In this scheme, the measurement of PM particles was carried out, as can be seen in table 3. These measurements were included in the test report 3044. These results were obtained, as well as those that will be presented later in different working conditions: namely 50%. 75% 100% of pump input power and fan output power.

9.4.2 Measurement of the physical parameters of the residual gaseous effluent and the geometrical parameters of the punctiform emission source

In the presented working conditions, two series of measurements were carried out, which are presented in tables 3 and 4. As can be seen from both tests, carried out on two different days, in the presented viscose conditions, the particle sizes measured at the exit from the filtration system with ultrasound are at the level of 1.6 μm, a level below the accepted values of PM 2.5.

Tab.3 The physical parameters of the residual gaseous effluent and the geometrical parameters of the puctiform emission source - the first series of measurements.

Working area	Source	Dimensions** [µm]	Area** mp	Spee m/sec.	Volumetric Debit	
		P.M. G.E.	P.M. G.E.	P.M. G.E.	mc/s	Nmc usc/s
Air Ultrasonic filtration system	Before the filter 50% of the power After the filter 50% of power	Med 1.6	Med 0.02 0.1	Med 1.5 2.3	0.038	0.019688
	Before the filter 75% of the power After the filter 50% of power	Med. 1.6	Med 0.020 1	Med 2.9 2.2	Med 0.051	Med 0.037575
	Before the filter 100% of the power After the filter 100% of power	Med 1.6	Med 0.020	Med 3.5 2.3	Med 0.058	Med 0.0365
				±10	±5	±15

Table 4 presents the physical parameters of the residual gaseous effluent and the geometrical parameters of the puctiform emission source. - the second series of measurements

Tab.4 Parametrii fizici ai efluentului gazos rezidual şi parametrii geometrici ai sursei puctiforme de emisie

Working area	Source	Dimensions** [µm]	Area** mp	Spee m/sec.	Volumetric Debit	
		P.M. G.E.	P.M. G.E.	P.M. G.E.	mc/s	Nmc usc/s
Air Ultrasonic filtration system	Before the filter 50% of the power After the filter 50% of power	Med. 1.6	0.0201	Med 2.65	Med 0.043	Med 0.026
	Before the filter 75% of the power After the filter 50% of power	Med 1.6	0.0201	Med 2.75	Med 0.055	Med 0.033
	Before the filter 100% of the power After the filter 100% of power	Med 1.6	0.0201	Med 3	Med 0.06	Med 0.037
Incertitudine extinsă relativă k=2, %		-	-	±10	±15	

*- Debite volumetrice calculate
**- încercări neacoperite de acreditarea RENAR

In care P.M. – punctul în care s-au efectuat măsurătorile, G.E. – gura de evacuare în atmosferă

H – the height of the point source, from the ground to the outlet from the atmosphere

The values emitted into the atmosphere at point sources are centralized in table 4 and refer only to the samples subjected to the test. Pollutant sampling/measurements totaled 50 min/source. The table shows the types of pollutants whose quantity was measured, namely:

- powders in suspension;
- volatile organic compounds VOC/TOC;
- nitrogen oxides NOx

In order to achieve an optimization of the air filtration technological process using the acoustic cavitation phenomenon, measurements were made under certain conditions. These conditions assume both the power of the pump that introduces the pressurized air to be filtered and the power of the fan to extract the air that has been filtered. Thus, for both input and output variables of the air filtration system, percentages of 50%, 75% and 100% of the working power (pressure) of the pump and the extraction fan were considered. This was considered necessary from two points of view:

- of the air introduction pump, which must be filtered, under pressure, since too low a pressure cannot help the penetration of pollutants inside the water in the filter tank, and too high a pressure can create turbulence inside the tank, which means a considerable decrease in the performance the ultrasonic cavitation process;
- of the filtered air extraction fan as there is a possibility that it cannot easily leave the liquid in the tank due to the atmospheric pressure exerted by the atmosphere on the free surface of the liquid. On the other hand, too much depression created on the surface of the liquid by the fan, due to the turbulent flow of air, can create turbulence in the volume of the liquid that prevents the ultrasonic cavitation phenomenon from occurring. In this sense, three steps were also considered, respectively at 50%, 75% and 100% of the fan's operating power.

For each of the resulting combinations and presented in table 9.8, different values of the concentrations of pollutants remaining after the air filtration process resulted. Thus, it can be seen that all the recorded values are below the admissible limits established by the national and European standards.

Tab. 5 Emission values in the atmosphere at the point source from TOP Lac Service Cotroceni

Working area/facility	Source	Pollutant	U.M.	Concentrațion				Permissible limit values
				After the filter 50%	After the filter 75%	After the filter 100 %	Arithmetic mean	
Ultrasonic air filtration system	Before filter 50% of power	Powders	mg/Nmc	0.68	0.44	0.42	0.5133	50 mg/nmc
		COV/COT*	mg/Nmc	20	18	20	19.33	100 mg/nmc
		NOx	mg/Nmc	0.1687	0.1831	0.1485	0.1667	350 mg
	Before filter 75% of power	Powders	mg/Nmc	0.46	0.42	0.41	0.43	50 mg/nmc
		COV/COT*	mg/Nmc	22	19	18	19.666	100 mg/nmc
		NOx	mg/Nmc	<0.1364	< 0.1365	< 0.1312	<0.1347	350 mg
	Before filter - 100 % of power	Powders	mg/Nmc	0.75	0.74	0.74	0.7433	50 mg/nmc
		COV/COT*	mg /Nmc	26	26	24	25.33	100 mg/ nmc
		NOx	mg/Nmc	<0.1363	<0.1369	<0.1362	<0.1364	350 mg

From the first set of measurements, it can be seen that obtaining minimum values of pollutants and impurities in the industrial air that must be filtered can be achieved under certain conditions. If they are averaged, the optimal operating values are those when the pump that introduces the air to be filtered operates at 75% of power and when the depression obtained with the air extraction fan is maximum, i.e. when it operates at maximum power.

In order to see if the filtration system works at the parameters that presuppose a filtration corresponding to the norms in force, a second set of determinations was made under the same technological conditions. Table 6 presents a second set of measurements of industrial air pollutants.

Table 6 Emission values in the atmosphere at the point source from TOP Lac Service Cotroceni – set 2

Conclusions

Last parte of the PhD Thesis starts with brief presentation of the problems caused by VOC emissions and the fact that this type of emissions exists even when water-based paints are used. It continues with "National and European regulations regarding the generation of volatile organic compounds" where the national and European legislation regarding the limit values of pollutant emissions that can be found at the level of car repair shops. I presented as follows:

- Maximum limit values for the content of volatile organic compounds for

Working area/facility	Source	Pollutant	M.U.	Concentration				Permissible limit values
				After filter 50%	After filter75%	After filter100%	Arithmetic mean	
Sistem de filtrare cu ultrasunete	Before filter 50% of power	Powders	mg/Nmc	0.28	0.27	0.29	0.28	50
		COV/COT*	mg/Nmc	12	11	12	10.67	100 mg/nmc
		NOx	m/Nmc	< 0.136	0.136	0.1372	< 0.1364	500
	Before filter 75% of power	Powders	mg/Nmc	0.23	0.22	0.25	0.23	50
		COV/COT*	mg/Nmc	11	12	10	11	100 mg/nmc
		NOx	mg/Nmc	<0.1364	0.136	0.1373	<0.1364	500
	Before filter 100% of power	Powders	mg/Nmc	0.22	0.21	0.23	0.21	50
		COV/COT*	mg/Nmc	10	10	11	10.33	100 Mg/nmc
		NOx	mg/Nmc	<0.1363	0.136	0.1373	<0.1363	500

- vehicle surface refinishing products

- Method allowed for products with a VOC content of less than 15% by mass in the absence of reactive diluents
- Methods allowed for products with a VOC content greater than or equal to 15% by mass in the absence of reactive diluents
- Method allowed for products containing VOCs in the presence of reactive diluents

In the last chapter of the thesis presents the pollutant measurements from the tin shop repair shop and paint shop, which were carried out by the company Givaroli SRL, the company that possessed all the necessary accreditations to carry out the measurements performed. They were measured as follows :

- pH
- suspended matter
- CO2
- CBO5
- solvent extractables
- detergents-anionic surfactants
- material particles
- VOC/COT*
- NOx

For all these determinations, the working conditions were also measured, such as *:*

- pressure
- humidity
- temperature
- air flow
- air speed at the entrance to the ultrasonic filtration system

In order to prove the viability of the new industrial air filtration system by ultrasonic cavitation, we designed a quality measurement system that includes the entire range of necessary measuring devices. Following the measurements, we found that the ultrasonic filtration system based on the cavitation phenomenon corresponds to the functional role for which it was designed and made.

With this measurement system, the variation of the air flow was achieved both before the air filter and after the air filter at powers of 50%, 75% and 100% respectively of the capacity of the air pump and of the fan used to extract the filtered air.

In order to obtain the optimal operating conditions of the created filtration system, we plotted several variation curves of the measured pollutants from which we obtained an average of operating in optimal conditions, with maximum efficiency.

Using the system designed and realized experimentally, an air quality was found that falls within the pollution limits accepted at national and European level, the Romanian legislation being a transposition of the European one.

It can thus be said that the air filtration system based on the production of the ultrasonic cavitation phenomenon more than fulfills the functional role for which it was designed, the results obtained being below the values imposed by the national or European regulations, sometimes even far below their limit. According to Law 462/1993, the permissible limit values are for:

- VOC – 100 mg/nmc;
- NOx – 350 mg
- Powders - 88 mg/l

All measurement values and admissible limits are presented in tables 3,4,5,6.

Taking into account all that has been presented so far, it can be said with certainty that the new industrial air filtration system based on the phenomenon of ultrasonic cavitation fulfills its functional role, bringing at the same time certain advantages, compared to clasic air filtration systems, such as life expectancy of years, operation without affecting the health and safety of people's work, much smaller dimensions compared to classic filters, the possibility of being oriented precisely in highly polluting areas, simple operation, costs that amortize over time.