Experimental results regarding industrial filtration using ultrasonic filters

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Abstract. The paper presents general description of an ultrasonic air filter used in industrial air filtration system and the experimental results obtained. The method can be used in air purification system from the highly polluting processing technology of an industrial shop (paint shops, foundries, welding constructions, forging, etc.). The ultrasonic system construction and the advantages of using ultrasounds in the pollutant air filtration and purification process and an ultrasonic filter designed are here presented. In this case, the transducer which is the most important element consist in two asymmetrical passive elements (reflector and radiant element). For the ultrasonic system design there are presented the principal theoretical elements and in the final the finite element analyze of the whole ultrasonic system. To start a different filtering system some considerations like the following are important: the construction should be as simple and easy to install in the working zone, do not require dismantling to clean the filter element, cleaning periodically when the pressure drop reaches a limit value by commanding the operation of the ultrasonic transducer, allow restraint of the finest particles leading to the final consumer (in some technological processes) pure air, have a much longer operating life than conventional filters, in the sense that the ultrasonic activated filter elements have a higher reliability, to achieve a pressure drop in a range of restricted values, practically to be kept constant or with very small variations, creating stationary waves to allow not only very fine particle retention but also air drying, allow easy maintenance, the operating costs of which do not exceed the costs of the classic ones.

1. Introduction
The article presents environmental concerns by finding new methods and solutions to increase the efficiency of air filters used in the industrial environment. The practical applications and achievements were carried out in a Bridge-Grant project that aimed at designing an ultrasonic air filtering system as part of a technological painting process performed by industrial operator in painting shops. The activity was carried out with the support of Universal Service SRL, which was part of the consortium of the project as a beneficiary. The commercial company is the main producer of painting shops in Romania, having many types of cabins in its portfolio, from the smallest to the cabin for painting trucks.

The research was based on the authors' activity in theoretical and experimental field of production and propagation of ultrasounds in different environments. One of the ultrasound applications has been proposed and demonstrated to be industrial the air filtering by using vibrations in the ultrasonic field, which in this case is represented by a disk in which very small holes have been made. The air filtration process is based on some of the ultrasonic properties such as:
compressing and scaling the environment according to the nature of ultrasonic waves;
- diffraction and diffusion of ultrasonic waves; attenuation of ultra-acoustic energy;
- ultra-acoustic absorption.

Considering these is proposed to use the effects of wave propagation in the filtration and purification process and the construction of ultrasonic filters operating on the principle of "ultrasonic agglomeration" on the principle of "ultrasonic shaking" [1-6].

2. General information on the use of ultrasonic wave air filters. Ultrasonic filters used in automotive painting shops

To eliminate the disadvantages of using classic filtering systems based on glass fiber filters, asbestos and other materials profoundly harmful to the health of human operators who, in time, lose their filtering capability by solid particle agglomeration, it has been implemented in the painting shops the filters based on the passage of air to be purified through a disk, with very small holes, that vibrates in the ultrasonic field. This filtering system has the advantage, besides the quality of the purified air, that it can be integrated very well into the actual metallic structure. One of the types of painting shops produced by Universal Service SRL is presented in figure 1. In the left side of this cabin there is the outside air suction column which is at well-established time intervals the air ventilation column of the cabin structure.

![Figure 1. Air filter system used in automotive paint shop.](image)

In this way, the maintenance of the filtration system is very good, easy and overlaps over its main feature, namely the possibility of ultrasound filtration system to greatly reduce the amount of pollutants emitted into the atmosphere.

The schematic of the ultrasonic filtration system is presented in figure 2. It consists of two parts [7]:
- the ultrasonic transducer that transforms the electric oscillations into mechanical oscillations in the range $f = 17 \ldots 100$ KHz. These oscillations are reflected and then amplified and transmitted to the conical ultrasonic concentrator.
- in the final part of the construction there is the vibrating disk with a very fine network of holes fixed at the end of the conical concentrator. The diameter of the holes is $d = 0.2$ mm. The disk performs mechanical oscillations of ultrasonic frequency and the air passing through the holes (figure 5) is cleaned in over 96%. Very small impurities resulted from the air filter functioning are collected in the
tank. These small elements fall into the extreme, inferior part of the system, by gravitational force, and get inside it. For additional mechanical cleaning, after the air has been passed through the disk with holes, it is passed through the cylindrical particle filter.

Since the diameter of the holes in the perforated disk is very small, there is a danger that they may become clogged with the micro-particles of the air to be cleaned. This will not happen because of the phenomenon of ultrasonic shaking that will always keep the holes inside the disk very clean. This type of ultrasonic filter works in vertical position, but in the figure 2, the presentation is in the horizontal position considering the article presentation [7-9].

![Figure 2. Ultrasonic filtering system.](image)

3. Practical realization of the ultrasonic air filter

According to the schematic diagram presented in figure 2, the main constructive elements of the ultrasonic filter, elements to be presented in this article are:

1. ultrasonic transducer;
2. ultrasonic amplifier;
3. vibrating disc with holes;
4. nodal flange
5. filter fixing and operational exhaust piping.

Figure 3(a) shows the schematic diagram of the ultrasonic transducer and in figure 3(b) its practical realization. Ultrasonic transducer consists in: piezo ceramic element, reflector, amplifier, and coupling element. Since the energy produced by the ultrasonic transducer has to be concentrated in the disk area with holes that will vibrate in the ultrasonic frequency range, figure 4(a) shows the projected ultrasonic concentrator and in figure 4(b) its practical realization.

![Figure 3. (a) - Schematic design of the ultrasonic transducer; (b) - practical realization of the ultrasonic transducer.](image)
The active element of this ultrasonic system is the disc with holes. Mounting the disc is done at the top of the ultrasonic concentrator so all the ultrasonic energy is focused on it. When air passes through the disc holes, very small holes due to vibrations in the ultrasonic field will produce industrial air filtration. The schematic diagram of the disc is shown in figure 5(a), one of the useful vibration modes in figure 5(b) and its practical manufacturing in figure 5(c).

A very important element of the ultrasonic system is the nodal flange. This element will fix the vibratory system into the air filter column. On the other hand, its position in the filter system has to be calculated so that in the point in which it is fixed with the transducer-amplifier-disk system with holes the oscillation amplitude is equal to zero. Otherwise, part of the oscillation energy will be transmitted and will be lost externally, in the air operation piping. A second negative effect would be that the entire structure will start vibrating in a totally unwanted way. In the figure 6 the nodal flange fixation on vibratory system is presented.

Figure 4. (a) - Geometrical shape of the ultrasonic concentrator; (b) - practical realization of the ultrasonic concentrator.

Figure 5. (a) - schematic of the disk with holes; (b) - dick vibration at frequency $f = 18365$ Hz; (c) - manufacturing of the disk with holes.

Figure 6. Practical mounting on ultrasonic system.
As noxious industrial air and paint particles are exhausting from the painting booths through a piping outside it, the ultrasonic filtering system will also be located in this area. Figure 7 shows the realization of this column before it is inserted into the structure of the painting shop.

![Figure 7](image)

**Figure 7.** The piping into which the ultrasound filtering system is attached.

### 4. Experimental measurements of filtered air quality using the ultrasonic vibration air filtration system

To measure the quality of filtered air with the new system, measurements were made according to an experimentally established methodology and in accordance with MAPPM Order no. 462/93, H.G. 1218 2006 and H.G. 355/2007 under normal technological conditions using an experimental stand MEGALYZER 9600 with standard equipment and a series of other necessary sensors. The results are presented in table 1.

| Day no. | Measured value |
|---------|----------------|
|         | NO₂ ppm | SO₂ ppm | CO ppm | NOₓ ppm | Acetone mg/mc | powders mg/mc | butyl acetate mg/mc |
| 1       | 0.2     | 0.5     | 4      | 1.6     | 10          | 0            | 1.2                |
| 2       | 0.3     | 0.4     | 6.2    | 1.8     | 15          | 1            | 2                  |
| 3       | 0.25    | 0.9     | 4.3    | 1.6     | 13          | 0            | 2.9                |
| 4       | 0.32    | 1.1     | 5.8    | 1.7     | 16          | 2            | 3.1                |
| 5       | 0.48    | 0.36    | 3.9    | 1.5     | 17          | 2            | 2.1                |
| 6       | 0.53    | 1.5     | 3.6    | 2.4     | 13          | 0            | 2.2                |
| VLE     | 10      | 1515    | 30     | 50      | 1210        | 10           | 150                |
| Medium Concentration | 0.257 | 0.373 | 3.83 | 1.97 | 13.4 | 0.235 | 1.75 |

| Day no. | Measured value |
|---------|----------------|
|         | Cumulative     |
| 1       | 98%            |
| 2       | 98%            |
| 3       | 96%            |
| 4       | 98%            |
| 5       | 96%            |
| 6       | 99%            |
| VLE     | 99%            |

### Table 1. Concentrations of noxes and suspended particles in the exhaust air from the painting shop using the ultrasonic filtering system.

#### 5. Conclusions

Following the analysis of the results obtained by the measurements, the following conclusions can be drawn:

- Many technological pollutants (NO₂, SO₂, CO, NOₓ, acetone, xylene, toluene, hydrocarbons, butyl acetate, butyl alcohol, tropospheric ozone, powder in suspension, dust, etc.) depending on the type of substances used for painting, sanding, welding, grouting of surfaces to be painted.
- It is noted that there are no exceedances of the limit measured values for any polluting substance in the case of using of the ultrasonic vibration filtering system, the degree of retention being in the range of 96 ... 99%, in some cases (powders in suspension) even 100% on some days as presented in table 1;
The ultrasound filtration system also has the advantage that it does not require as often as the classic system, disassembling and changing the filter cartridge because self-cleaning by ultrasonic vibrations takes place; 
Taking into account the high cleaning degree obtained using the ultrasonic vibration filtering system, it is also recommended to use it in other areas.

6. References
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