Researches concerning the construction of ultrasonic gas filters

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Abstract. The paper presents a detailed analysis of the main disadvantages presented by the classic devices of filtration and purification of gases of any nature. Following the analysis of the main phenomena that occur in the propagation of ultrasounds through a gaseous medium: propagation velocity; compressing and scaling the environment according to the nature of ultrasonic waves; reflection and refraction of ultrasonic waves at the solid-gas interface; the creation of stationary waves and the emergence of pressure knots and antinodes; diffraction and diffusion of ultrasonic waves; attenuation of ultra-acoustic energy; ultraacoustic absorption; ultrasonic cavitation, etc. it is proposed to use the effects of their 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" or combined. The design of an ultrasonic filter in such a way that stationary waves allow it to retain the finest dust particles because in the pressure antinodes there is a phenomenon of coalescence involving the addition of fine particles to a larger particle (> 10 μm) which no longer represents a retention problem such that an ultrasonic filter has a retention depth of nearly 100%. During the propagation of the ultrasonic waves in the gaseous medium, compressions and dilatations are produced and the compression zone temperature becomes higher than in the scraping zone and hence in the depression area the extraction of the water from the environment takes place and in the compression zone it is being vaporized, therefore air drying is also carried out. By "ultrasonic agglomeration" of fine particles, their initial mass increases by coalescence of 2500 to 3500 times compared to the mass of the primary particles, being easily captured by the filter element, and by "ultrasonic shaking" the phenomenon of stomping of the cartridge filtering or clogging, performing cleaning during operation, without requiring interruption of gas transport and removal of the filter. Experimentally it was found that for a maximum filtration depth, increased efficiency of the filtration and purification process, a logical sequence of ultrasonic filters fitting their possibilities to completely retain the solid particles, to remove the water particles and to dry the gases. In the paper are presented four types of ultrasonic filters with possible use in gas filtration and purification: cyclone ultrasonic filter, vertical ultrasonic filter, ultrasonic horizontal conical filter and final ultrasonic filter, with their advantages and disadvantages.

1. Introduction

For process elimination of solid impurities from existing gases in different spaces, dust filters are used, which according to the principle of operation can be: gravimetric separators; centrifugal separators; separators by sudden reduction in speed; separators by washing; filters; separators in the electric field; separators by coalescence; special separators. In addition to solid particles of different shapes and sizes, gases also contain a series of gases such as hydrogen sulfide, ammonia, carbon...
dioxide, mercaptans, sulfur dioxide and others, which, in order to avoid atmospheric pollution, require proper purification.

Usual gas purification processes can be based on the following processes or unitary operations: absorption into a liquid called absorbent, absorption on a solid material called sorbent, fractionation, crystallization and filtration, chemical conversion of impurities, special processes. The most commonly used gas filtering and purifying devices are filters [1,2,3,6,7] of different shapes and categories, which are characterized by the following elements: the gas flow transported and which are taken over by the filters; the particle diameter that can be retained; the maximum temperature of the gases brought into the filters; the degree of retention or the efficiency of the filter; loss of pressure in the filter; annual maintenance costs. In order to reduce some of the drawbacks of classical filters and to substantially improve the gas filtration process, the research contained in this paper proposes the use of ultrasonic waves in the filtration and purification process, following the analysis of the main phenomena occurring in the propagation of ultrasonic waves through a gaseous medium.

2. Design of ultrasonic filters that makes improvement of air filtering processes

The propagation of ultrasonic waves in a solid [4,5,8,9] and liquid particulate carrier gas environment is of great practical importance in determining the main phenomena and especially the effects that occur during the ultrasonic activation of the space through which the gases flow at a so-called flow rate. Knowing the particularities of ultrasonic wave propagation in the gaseous medium will allow the design of ultrasonic filters with certain design and operating characteristics.

Analyzing the main phenomena and effects of ultrasound propagation through gaseous media and taking into account the kinetics of the natural gas filtration process, a series of filters were designed and tested to perform the filtration and design operation with increased efficiency and under the conditions of a higher economic efficiency. In choosing the filtering method and the appropriate filter, the following were considered:

- the construction is as simple and easy to install in the appropriate areas;
- not require dismantling to clean the filter element, cleaning periodically as soon as the pressure drop reaches a limit value by commanding the operation of the ultrasonic transducer;
- allow the restraint of the finest particles resulting in pure natural gas to the final consumer (in some technological processes);
- 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 across a range of restricted values, practically to be kept constant or with very small variations;
- to create stationary waves to allow not only the retention of very fine particles but also the drying of the gases so that in the measuring, checking and metering instruments the natural gas will flow without impurities and dry;
- allow easy maintenance, the operating costs of which do not exceed those of the classical ones.

Under these conditions, several models of ultrasonic filter are proposed, which through the shape and dimensions of the final element create the ultrasonic field corresponding to the desired filtration process.

2.1 Design and construction elements for a cyclone ultrasonic filter

This type of filter is designed in such a way that the body of the filter (figure 1) excites stationary ultrasonic waves and operates at resonance condition from time to time. Due to the achievement of a stationary field, coalescence phenomenon occurs and its depth and the depth of retention of this type of filter is very high. The fine and very fine particles are collected in the pressure nozzles where they form larger particles and then are trained on the outer trajectories being projected onto the filter wall and sent to the solid and liquid impurities drainage device. Also, ultrasounds during their propagation by making successive zones of pressure and depression will also lead to continuous extraction of
liquid or vapour present in the gas stream. The evaporation velocity at the boundary surface between the liquid in gases and gases $v_{ev}$ is determined with a relation of the form:

$$v_{ev} = \frac{k \cdot S(P - p)}{p_0}$$  \hspace{1cm} (1)

where: $P$ is the saturation pressure of the vapor at the temperature of the liquid; $p$ - vapor pressure in natural gas; $p_0$ - gas pressure; $S$ - surface of solid impurities; $K$ - coefficient which depends on the degree of turbulence of the gas above the liquid-gas separation surface.

Apart from this phenomenon, ultrasounds still produce intense gas turbulence at the surface level of solid impurities, thereby increasing the evaporation rate. The most important part of this FUC 01 ultrasonic filter is the ultrasonic system, because of its construction and its size depends on the operation and efficiency of the filter.

This type of ultrasonic design proposed the elimination of the cleaning step of the filter element after clogging. In this case (figure 2), the filter element forms the common body with the final active part of an ultra-aoustic system. The great advantage of this type of filter is that it enters into operation when the active element is clogged and the pressure drop has reached a certain limit value by commissioning the ultrasonic generator and the ultrasonic system respectively.

**Figure 1.** Cyclone ultrasonic filter, model FUC 01: 1 - impure gas inlet pipe; 2 - cyclone filter wall; 3 - helical current; 4 - solid impurities; 5 - decantor wall; 6 - leakage device for solid and liquid impurities; 7 - liquid droplets; 8 - dust deposited on the filter walls; 9 - sealing ring; 10 - radiant disc; 11 - ultrasonic energy concentrator; 12 - nodal flange; 13 - ultrasonic transducer housing; 14 - radiating element; 15 - reflector element; 16 - acoustic insulation; 17 - PZT discs; 18 - purified exhaust pipe.
Figure 2. Vertical ultrasonic gas filter, model FUV 01: 1 - impure gas inlet pipe; 2 - fastening flange; 3 - fixing pipe; 4 - the filter wall; 5 - the active filter element; 6 - ultrasonic energy concentrator; 7 - filtration holes; 8 - the filtered gas circuit; 9 - Purified exhaust pipe; 10 - grip flange; 11 - dust particles; 12 - collector; 13 - purge valve; 14; 15 - sealing rings; 16 - nodal flange; 17 - radiating element; 18 - piezoceramic discs; 19 - reflector element; 20 - acoustic insulation.

The duration of operation is virtually unlimited, given the lifetime of the active element of the filter. Determining the vibration modes useful in the operation of a vertical gas filtering system is very useful as it can give complete information on the operating frequencies of the ultrasonic system and its vibration modes.

2.2 Design and construction elements for a horizontal ultrasonic cone filter
This type of filter is conceived in a construction corresponding to a classic conical filter, but which allows total containment of the liquid particles present in natural gas. The ultrasonic system is designed and calculated to operate in resonance mode, its entry into operation being when the pressure drop on the active filter element reaches a limit value that controls the commissioning of the ultrasonic generator and the ultrasonic system respectively. The final part of the ultrasonic system (figure 3) comes in direct contact with the active filtering element (cartridge) allowing its "ultrasonic shaking", avoiding the clogging or clogging of the filter cartridge. Such a construction allows continuous operation of the filter, the lifetime of the filter being given by the life of the filter cartridge. This type of filter also has the advantage that being in a horizontal position allows the holding of the liquid
particles and their discharge together with the solid impurities. The depth of the filter retention depends on the dimensions of the filter element mesh. The computational and construction elements of the ultrasonic system are similar to those described above, with the vibration modes being in the range of $f = 18.5 \ldots 22.8$ KHz.

![Diagram](image-url)

**Figure 3.** Horizontal cone-shaped ultrasonic filter, FCOU model 01: 1 - gas inlet pipe; 2 - the clamping flange; 3 - soles filter; 4 - holes; 5 - filter cloak; 6 - conical filter; 7 - holes; 8; 9 - fixing flange; 10 - ultrasonic energy concentrator; 11 - nodal flange; 12 - radiant element; 13 - piezoceramic discs; 14 - reflector element; 15 - housing; 16 - Purified exhaust pipe; 17 - acoustic insulation; 18 - leakage ramp.

3. Conclusion
The filtering operation depends on many factors, the most important being the following: the inlet pressure in the filtering device; the gas flow to be filtered and purified; nature and size of solid particles; shape and size of solid and liquid particles; gas flow and trapped dust density; operating temperature; filter depth; the level of filtering; operating mode;

The particularities of the ultrasonic wave propagation in the gas environment that drives the solid and liquid particles depend on the phenomena and the effects that arise due to the creation of the ultrasonic field, namely the propagation velocity; compressing and scaling the environment according to the nature of ultrasonic waves; reflection and refraction of ultrasonic waves at the solid-gas interface; the creation of stationary waves and the emergence of pressure knots and antinodes; diffraction and diffusion of ultrasonic waves; attenuation of ultra-acoustic energy; ultraacoustic absorption; ultrasonic cavitation etc;

Designing an ultrasonic filter in such a way that stationary waves allow it to retain the finest dust particles because in the pressure antinodes there is a phenomenon of coalescence involving the addition of fine particles to a larger particle (> 10 μm) which does not it is also a retention problem, so that an ultrasonic filter has a retention depth of nearly 100%;

During the propagation of the ultrasonic waves in the gaseous medium, compressions and thinners are produced and the temperature in the compression zone becomes higher than in the sparging zone and consequently in the depression zone the extraction of the water from the environment takes place and in the compression zone it occurs its vaporization;
Through the “ultrasonic agglomeration” of the fine particles, their initial mass increases by coalescence of 2500 to 3500 times compared to the mass of the primary particles, being easily captured by the filter element;

By means of “ultrasonic shaking”, it is avoided the phenomenon of clogging of the filter cartridge or clogging it, performing cleaning during operation, without requiring the interruption of the gas transport and the removal of the filter;

The most important part of any ultrasonic filter is the ultrasonic system that must be calculated, designed and executed in such a way as to produce a stationary wave field (ultrasonic cyclone filters) or work in resonance mode (the case of the other types of filters);

An ultrasonic filter automatically enters the operation when the pressure drop has reached a certain limit (previously adjusted) by operating the ultrasonic generator or the ultrasonic system which produces the ultrasonic shaking of the filter element until the pressure drop is the initial;

Ultrasonic filter does not require periodic disassembly and cleaning, its operating life being given by the lifetime of the filter element that is subjected to the “ultrasonic shaking” phenomenon whenever needed.

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