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# EVALUATION OF THE SONIC SYSTEM EFFICIENCY FOR RAW WATER TREATMENT

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## ABSTRACT

*Water pollution is defined as the change in the water composition that is harmful to human health, unsuitable for economic use or reactive and that can cause damage to the aquatic flora and fauna. In the appreciation of the World Health Organization, appreciation, approximately 2/3 of illnesses are due to polluted water, and the main pollutants come from industry. The paper presents an analysis of the technical systems used for raw water decanting with a view to making it drinkable.*

KEYWORDS: raw water, clarifier, sonic, ultrasonic, efficiency

## 1. Introduction

Through their process wastewater, mining and metallurgy industries are the main source of pollutants, such as lead, zinc, copper, cadmium, arsenic, mercury and others. Heavy metals generally act on living organisms as toxic substances, causing inhibition of cellular enzymatic processes or causing numerous other physiological disorders.

Process wastewater is potentially dangerous for the environment, because of direct or indirect chemical reactions. Some process waters are already biologically degraded process and thus require immediate oxygen demand.

The most harmful substances in industrial wastewaters are organic substances, suspended substances, toxic substances and heavy metals.

The efficiency, of the wastewater treatment is defined by the relation:

$b = ((M-m) / M) * 100$

where M is the initial concentration of the substance and m, its concentration after treatment. Efficiency is usually calculated for suspended substances, organic substances (expressed in $CBO_5$), oxygen $O_2$, pH and toxic substances [1].

## 2. Unconventional water treatment technologies

The conventional water treatment technology involves successive stages of settling, chemical treatment filtration with material consumption, high energy and labor, aspects that determined more and more it replacement with more modern performative techniques.

Classic technologies present a number of disadvantages, reason for seeking alternative solutions to conventional processes, to eliminate these drawbacks and, in particular, to ensure a higher water quality.

Analyzing the technical systems for raw water decanting in view of making it drinkable, we can deduce that the most convenient solution is to use vertical clarifiers specific to the treatment of small and medium water flows (required municipalities below 10,000 inhabitants) which can be equipped with gas-dynamic sonic generators.

Concurrent processing with acoustic waves and aeration of technological is a liquids scientific novelty in the raw water treatment processes. Another novelty could be the coexistence with the helps of gas-dynamic sonic generators of two simultaneous processes: clarification (decantation) and disinfection. In the specialized bibliography it is recommended that the operating mode of ultrasonic systems to be intermittent. Using the sound and ultrasounds gas-dynamic generators can be beneficial to the process of aeration too because these devices enhance the diffusion of oxygen into the water and accelerate the chemical reactions between water and coagulant. Based on the analysis of types of generators the best can be considered the Lavavasseur generator type, which is stable in operation and can provide airflow sufficient working small working pressures (up to 0.5 bar - specific pressure turbochargers existing in water plants) to provide raw water aeration processes [3, 6, 7].

## 3. Sonic decantation device

Given the fact that decanters are uncovered devices which retain suspended substances gravimetrical sediment from the raw water to be treated, they are located upstream the filters.

The number of settlers in operation is at least 2 units.

Vertical decanters (Fig. 1) can be circular or square shaped in plan, where the water movement is inverted, vertically. They are used for low flow rates, maximum daily flow less than 10,000 m³ and diameters up to 10 m.

The working methodology in experimental research was as follows:

- develop a new method for calculating the gas-dynamic generators with two resonators and flat jet;
- developing the method for calculating the experimental vertical settler combined with accelerator type - ascending with the possibility to equip the sonic gas-dynamic generator;
- establish working arrangements for installations where the water flow is constant in the experimental decanter (raw water flow of 0.9144 m$^3$/h of raw water upward speed of 0.145 mm/s);
- establishing the flow solution of the coagulating agent (a dose of 40 - 60g/m³ aluminum sulphate $Al_2(SO_4)_3$);
- establishing the intermittent working cycle of the sonic generator, depending upward speed of water and the capacity of the experimental decanter (effective operating of the time sonic generator of 60 minutes, alternating with rest periods of 5, 10, 15 or 20 minutes) diving depth generator in the reaction chamber (0, 0.5, 0.75, 1 m) and the generator placement to the chamber (axial or tangential to the wall - central);
- adoption of existing methods of acoustic measurements.

The preliminary tests of the experimental sonic decanter showed the maximum effect of sonic treatment at a distance of 40 mm from the central axis of the reaction chamber, almost tangential to the wall (cylindrical) chamber [2].

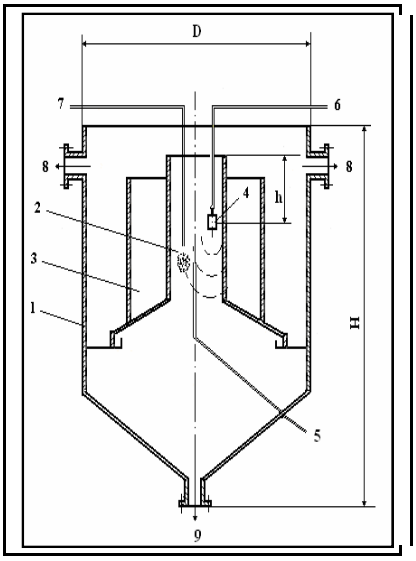


***Fig. 1.*** *Experimental sonic decanter: 1 - decanter wall; 2 - mixing chamber; 3 - reaction chamber; 4 - sonic generator; 5 - Line pipes for raw water, 6 - working air duct of the generator; 7 - coagulant pipe; 8 decanted water-collection; 9 - sludge collector; D, H – diameter, respectively, decanter height; h - generator depth.*

## 4. Influence of sonic generator operating mode with two resonators on physico-chemical and bacteriological quality parameters of raw water

Based on the experiments, the optimal ratio was determined between the period of operation of the generator and the rest period: $t_{rap}$ = 5min/15 min, set in an operating cycle of one hour, which is the average turbidity of $T_x$ = 2.56 NTU, and is lower than that obtained in the classical decanter (value between 4.2 and 4.8 NTU), which proves that the sonic decanter is more effective with 36.415% compared to a traditional decanter.

Due to the bi-acoustic frequency field (sonic frequency of 10.76 kHz ultrasonic frequency of 21.520 kHz), the following results were obtained:

- decrease of amount of water oxydisability (oxydisable organic substances) by 1.5 times compared to that obtained by conventional technology and 1.826 times compared to the raw water;
- reduction aluminum ions content in water of 1.66 times compared with traditional technology;
- decrease from 110 mg/L to 100 mg/L sulfate ion content in some water sonic decanted compared with classic decanting.

When replacing the sonic generator with an aerator in the experimental decanter, it was observed

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that the value of oxydisability of the water decanted is more than 1.3 times compared to water treatment with generator.

This confirms that in parallel with the aeration through bubbling, occurs the water degassing due to cavitational processes. The influence of sonic generator operating mode with two resonators on parameters of microbiological quality of raw water was also studied: aerobic mesophilic bacterial number (mesophilic), the probable number of coliform bacterias (total coliforms), the probable number of thermotolerant coliform (fecal coliform), and the probable number of faecal streptococcus.

The sonic treatment of water has a significant bactericidal effect. In all experiments it was observed that the bacteriological indicator values are "0". No matter the effective functioning of sonic generator (from cyclical variations) or the immersion depth of sonic generator. The microorganisms, the behavior under the influence of the ultrasonic generator, depend on cavitation.

Thus, if the germs and streptococcus are destroyed by pressure waves produced by sonic waves, then total and fecal coliforms are resistant to sonic waves but destroy themselves at the cavitational bubble implosion (the so-called phenomenon "hot spot"). Due to the acoustic bi - the frequency field (sonic frequency of 10.76 kHz and 21.52 kHz ultrasonic frequency, the overall level of 112.32 dB acoustic intensity), there is total destruction of microorganisms in water [4,5].

## 5. Evaluation of synergistic effect of the raw water sonic treatment

Suspension and the any type of impurities that may interact chemically are those which count in the calculation that underlies the decanters efficiency. Both water used in industrial processes and for drinking should have the turbidity, as small as possible, depending on the decantation level.

Based on measurements made at the experimental stand with a sonic decanter, decant water turbidity was determined at different doses of coagulant sulfate aluminum 4 mg/L (10%), 8 mg/L (20%), 12 mg/L (30%), 20 mg/L, (50%), 24 mg/L, (60%), 32 mg/L (80%).

As shown in Fig. 3, the lowest turbidity values are obtained for sonic treatment, water turbidity increasing with dose escalation to 10 mg/L (in solution: 50 mL/L) coagulant, then decreasing to 20 mg/L (in solution: 100 mL/L), after which the dose does not influence turbidity any more.

As shown in Figure 3 and Table 1 the lowest dose at which the control turbidity coincides with the sample turbidity is 0.2 mL/L of aluminum sulphate solution.

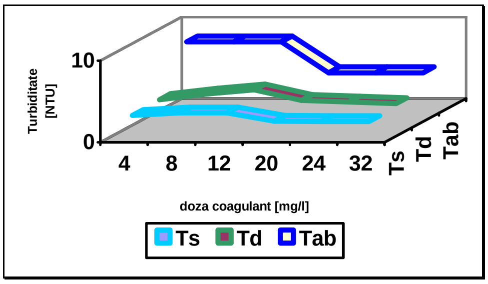


***Fig. 2.*** *Turbidity variation depending on the dose of aluminum sulphate: $T_s$ - turbidity at sonic treatment; $T_d$ - turbidity to classic decanter; $T_{ab}$ - raw water turbidity; D-dose of aluminum sulphate.*

***Table 1.*** *Variation of average turbidity values (control and working) depending on dose values of coagulant solution (aluminum sulphate)*

| Indicators | Coagulant dose solution | Average turbidity value - working | Average turbidity value - martor |
|---|---|---|---|
| | [mL/L] | [NTU] | |
| Values | 5 | 15.1 | 4.2 |
| | 4 | 14 | 4.1 |
| | 3 | 12 | 3.8 |
| | 2 | 6.4 | 4 |
| | 1 | 5.9 | 4 |
| | 0.8 | 6.1 | 3.9 |
| | 0.6 | 7.4 | 3.8 |
| | 0.4 | 5.9 | 4 |
| | 0.2 | 3.9 | 4 |
| | 0.1 | 5.2 | 3.9 |

Analysis of synergetic effect of sonic treatment on coagulant dosage was revealed by reducing the dose of coagulant required in the water treatment process. Based on experiments made in the sonic decanters with different doses of coagulant effective results were obtained for dose reduction with 50% aluminum sulfate and aluminum polihydroxiclorure dose with 40%.

## 6. Technical and economic efficiency system of the sonic raw water treatment

In water treatment plants for drinking water it is used during decanter, decanters batteries, in most cases of an even number of decanters, minimum 2 (double). We believe that the experimental sonic decanter is part of a battery of 4 such decanters required for treatment plants that supply a city (or a territorial administrative unit) of more than 10,000 inhabitants.

The price of a cubic meter of raw water (water of the Danube) purchased from "Apele Romane" National Company is considered to cost € 0.0148. The price for a cubic meter of drinking water in Braila, for the analyzed period, is 0.788 €.

The data presented in Table 2 show that the more we approach the area of the Danube flowing mouth into the Black Sea the more the price of drinking water from this source increases.

Implicitly, the closer the Danube approaches the flowing mouth, the more loaded it is and machining process requires additional costs, which are reflected in increasing doses of chemicals used: coagulants (aluminum sulfate, aluminum polyhidroxiclorure, polyelectrolytes) and disinfectants (chlorine).

***Table 2.*** *Price of a cubic meter of drinking water (obtained by treating raw water from river water) in different Danube areas*

| **Zone** | **Giurgiu** | **Alexandria** | **Craiova** | **Calarasi** | **Braila** | **Tulcea** |
|---|---|---|---|---|---|---|
| **Price,** lei/m$^3$ | 2.74 | 2.75 | 3.062 | 3.137 | 3.31 | 3.844 |

For waters from deep sources, the expenses with greatly reduced the use of chemicals decrease very much even below 10%, but increase on additional equipment to remove sand and various metals existing in deep water.

To treat raw water during the settling stage, aluminum sulfate (the treatment plant in Braila), aluminum polyhidroxiclorure (treatment plants in Chiscani and Gropeni) are used as coagulants, and one polyelectrolyte coagulation as an adjuvant.

To establish the effectiveness of modern methods of treating raw water with ultrasonic waves two specific situations are taken into consideration in which the type of decanters is different:

- sonic decanter using the bi-frequential gas-dynamic generator;
- classic decanter, where the aluminum sulfate is used as coagulant, and polyelectrolyte (polyacrylamide anionic) as an adjuvant.

Profit is calculated by taking into account certain formulas in the economic sphere, as follows:

Price-sales function: $p_{(x)} = a - b \cdot x$

Income function: $R_{(x)} = p_{(x)} \cdot x = (a - b \cdot x) \cdot x$

$p_{(x)}$ = price according to quantity; $x$ = amount; $R_{(x)}$ = profit.

Profit function: $\pi = R_{(x)} - C_{(x)} = (p \cdot x) - C_{(x)} = (p \cdot x) - (AVC \cdot x) - F$

where: $\pi$ = profit; $p_{(x)}$ = price according to quantity; $x$ = quantity; $AVC$ = average variable costs; $MC$ = marginal cost; $F$ = total fixed costs

$$\frac{\partial R}{\partial x_i} = p_i\left(1 - \frac{1}{|\eta_{xip}|}\right) \qquad (1)$$

where: $\eta_{xip}$ is the price elasticity.

In case of threshold, there are 2 situations:

a) the costs are covered (breakeven point): $\pi = R - C = 0$

b) critical amount of income (breakeven quantity): $x = \frac{C_f}{p - c_v}$

where: $x$ = quantity; $c_v$ = cost per piece, variable; $C_f$ = fixed costs total; $p$ = price per piece (x).

Cost is calculated using the formula [120]:

$$C_{tuf} = \frac{\sum_{i=1}^{m} C_{hi}}{Q_j}, \qquad (2)$$

where: $C_{tuf}$ = total unit cost; $C_h$ = finished production expenses; $Q$ = quantity of finished products; $i$ = item calculation; $j$ = object calculation.

To calculate the effective efficiency of the sonic decanter plant, it is following are considered: $V_a$, - volume of water decanted within an hour, m³; $n_d$ - number of decantation units; $n_g$ - number of sonic generators; $\tau$ - time of turbocharger operations, min; $n_t$ - number of operation of the turbocharger in an hour; $t_o$ - time necessary to 1 m³ of water decantation in the sonic decanter, h; $P_t$ - acting electric power turbocharger; $C_e$ - the cost of electricity, Euro/kW·h;

$C_{cg}$ - the cost of coagulant (aluminum sulfate), lei/kg; $C_p$ - coagulation adjuvant (polyelectrolyte) cost, lei/kg; $C_{Cl}$ - disinfectant (chlorine) cost, lei/kg; $C_g$ - sonic generator cost, Euro/pc; $C_{aCl}$ -chlorination unit cost, USD/pcs; $C_x$ - general expresses sonic treatment of raw water, lei; $d_x$, - the optimum dose of coagulant for sonic decanter, mg/L; $d_c$ - average dose of coagulant used in a classic decanter, mg/L; $M_x$ - decanted mass coagulant in sonic decanter, kg; $M_c$ - coagulant mass used in classic decanter, kg; $M_p$ - polyelectrolyte mass (coagulation adjuvant - flocculation) used in classic decanter, kg.

**1.** The calculation begins by determining electricity consumption ($W_o$) necessary to sonic decantation of water within one hour:

$$W_0 = P_t \cdot \frac{t_o}{\tau \cdot n_1}, \text{ kW} \quad (3)$$

where: $P_t$ = 3kW; $\tau$ = 5 min; $n_t$ = 3, $t_0$ = 1h = 60 min.

Results: $W_0$ = 0.75 kW.

**2.** Electricity costs for sonic decanters of 1 m³ of fresh water which decants within 1 h is:

$$C_0 = C_e \cdot W_0 \cdot t_0 = 0.0107 \text{ €}, \quad (4)$$

where: $C_e$ = 0.014 €/kW·h; $W_0$ = 0.75 kW ; $t_0$ = 1h.

**3.** Sonic electric energy cost of raw water settling in the 4 units dams, within 1 h is:

$$C_4 = C_0, \text{ €} \quad (5)$$

where $C_0$ = 0.0107 €.

**4.** Amount of coagulant (aluminum sulfate) used in the process of sonic decanters of 1 m³ of fresh water is

$$M_x = d_x / 1000 = 0{,}02 \text{ kg}, \quad (6)$$

where $d_x = d_c / 2$ = 20 mg/L.

**5.** Amount of coagulant (aluminum sulfate) used in the raw water pond SOIC within 1 h is:

$$M_{4x} = 4 \cdot M_x, \text{ kg} \quad (7)$$

where: $M_x$ = 0.02 kg.

6. Daily expenses for settling sonic raw water from the treatment plant (4 units tailings) are:

$$C_z = (M_{4x} \cdot C_{cg} + C_4) \cdot 24 = 0.6035 \text{ €} \quad (8)$$

where: $M_{4x}$ is 0.08 kg and the $C_{cg}$ is 0.3 € / kg.

7. General annual expenses for sonic raw water decanter under the above conditions are:

$$C_z = (M_{4x} \cdot C_{cg} + C_4) \cdot 24 = 0.6035 \text{ €} \quad (9)$$

where: $C_z$ = 0.6035 €; $C_g$ = 100 €/pc.

8. Annual profit obtained by sonic treatment of raw water in comparison with a classic treatment, as a treatment stand:

$$P_f = \{[( M_c \cdot C_{cg} + M_{Cl} \cdot C_{Cl}) \cdot 4 \cdot 24] \cdot 365 + M_p \cdot C_p + C_{aCl} \cdot 1 \text{ buc.}\} - C_x, \text{ €} \quad (10)$$

or $P_f = C_{gen} - C_x$ = 355.24 €

where: $M_c$ = 0.04 kg; $C_{cg}$ = 0.3 €/kg;

$M_{Cl}$ = 0.00416 kg; $C_{Cl}$ = 0.388 €/kg

$M_p$ = 10 kg (mean consumed in a year);

$C_p$ = 3.214 €/kg

$C_{aCl}$ = 476.2 € / pcs (average market)

$C_x$ = 620.3 €

$C_{gen}$ = 975.53 € (annual costs for treating raw water classic).

9. Sonic decantation efficiency (annual) in comparison with traditional decanting within the treatment stand is:

$$E_f = 100 - \frac{C_{gen}}{P_f} \cdot 100 = 36.415 \text{ \%}, \quad (11)$$

where: $P_f$ = 355.24 €.

The cost of water treatment by the classic method is 2.67% from the water cost (ie € 0.02 from 0.788 € - price for 1 m³ drinking water in Braila) due to sonic decantation efficiency ($E_f$ = 36.415%) the cost of water treatment by the sonic method represents 0.67% of the drinking water and the price obtained will be 0.772 € / m³.

## 7. Conclusions

We determined the ratio between the period of the generator operation and the break period = 5min/15 min, set in an operating cycle of one hour at which the average turbidity value = 2.56 NTU being of the $T_x$ and is lower than that obtained in the classic decanter (value between 4.2 and 4.8 NTU), which proves that the sonic decanter is 36.415% more effective compared with a traditional decanter.

The analysis of the synergetic effects of sonic treatment on coagulant dosage was revealed by reducing the dose of coagulant required in the water treatment process. Based on experiments made on the same decanter with different doses of coagulant, effective results were obtained for dose reduction the (by 50% aluminum sulfate and by 40% aluminum polyhidroxyclorure).

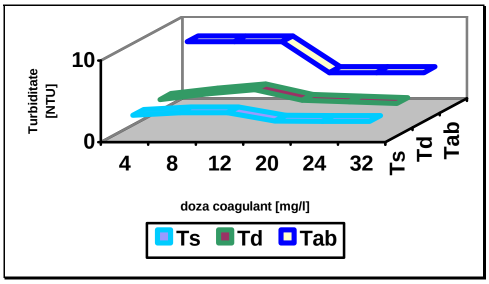


***Fig. 2.*** *Turbidity variation depending on the dose of aluminum sulphate: $T_s$ - haze at sonic treatment, $T_d$ - turbidity to settle fever; $T_{ab}$ - raw water turbidity, D-dose of aluminum sulphate*

***Table 1.*** *Variation of average values of turbidity (control and working) solution function coagulant dose values (aluminum sulphate)*

| Indicators | Coagulant solution dose | Average value of working turbidity | Average value of reference turbidity |
|---|---|---|---|
| | [ml/l] | [NTU] | |
| Values | 5 | 15.1 | 4.2 |
| | 4 | 14 | 4.1 |
| | 3 | 12 | 3.8 |
| | 2 | 6.4 | 4 |
| | 1 | 5.9 | 4 |
| | 0.8 | 6.1 | 3.9 |
| | 0.6 | 7.4 | 3.8 |
| | 0.4 | 5.9 | 4 |
| | 0.2 | 3.9 | 4 |
| | 0.1 | 5.2 | 3.9 |

In the final price of water distribution to users, water treatment represents a very small percentage (less than 3%), but in the case of the sonic water treatment it becomes lower than 1%, which shows the efficiency and profitability of this new raw water treatment technology for obtaining drinking water compared to the conventional technology.

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