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[1.] Lorand TOTH, [2.] Angelica DRAGHICI, [3.] Marius KOVACS,
[4.] Maria PRODAN, [5.] Andrei SZOLLOSI-MOȚA

DESIGN OF A WASTE WATER CLEANING EQUIPMENT ON THE HYPOBARIC FLOTATION PRINCIPLE

[1-5.] INCD INSEMEX PETROSANI, ROMANIA

ABSTRACT: The explosive increasing of the world population, the high urbanization, as well the development of certain industries that use large amounts of water during the engineering processes have triggered the depletion and the pollution of water resources. With the view to protecting people's health and the surrounding environment, the discharge of waste/polluted waters into the sewerage system and into the natural flowing waters shall be in accordance with the legislation in force. In order to diminish the pollution level of emissaries due to the uncontrolled discharged of waste waters, these polluted waters shall have to be cleaned. There has been developed a pilot installation for hypobaric flotation cleaning. Optimizing the cleaning of waste waters has been performed with the help of a transformation matrix for a three-factor test in a semi-replica. Taking into consideration the parameters of the component elements of the pilot installation, there has been designed an industrial installation for the cleaning of waste waters with a supply flow rate of 100 m^3/h with the help of hydrodynamic modeling and similitude criteria. It was possible to settle the aeration device the hydro-aerator and the flotation cell with the following component parts: the adhesion tube, chamber acceleration and the body of the flotation cell.
KEYWORDS: waste water, cleaning, hypobaric flotation, experiment, flowchart

❖ INTRODUCTION

All through the time, water has been used on an increased basis and for different purposes: for drinking, sanitation, house needs, fishing, navigation, irrigation operations, engineering processes.

On the other side, the outburst of world population, high urbanization level, as well the coming of highly consuming water industries with adverse effects both over water and over the surrounding environment has triggered a double - sided phenomenon called “water depletion and pollution” [5].

The calculations show that every 15 year, the water consumption doubles and mainly the freshwater consumption that spreads the water crisis all over the world [6]. With the view to protecting people's health and the surrounding environment, the discharge into the sewerage system and into the natural receivers of industrial and house wastewaters with a high content of polluting substances is made in accordance with the requirements of the legislation in force, i.e. the Law of Waters no. 107/1996 and the Government Decision no. 188/2002 (NTPA 001, 002 /2002) [8,9].

Subsequently, this paper intends the support the cleaning of the waste waters because “water is not a trading item as any other thing but a a heritage that has to be preserved and protected” (Framework Directive 200/60/EC).

❖ WASTE WATER CLEANING METHODS

There are several situations when it is used flotation to clean the industrial waste waters, for example the waters discharged by oil industry, mining industry, food industry, especially when the waters have to be biologically treated [1].

Air flotation can also be used to remove very fine solid particles from water: these particles shall adhere to the air bubbles and subsequently conveyed to the surface of the water. In this situation flotation turns into a complex physical and chemical process, as it has to provide a hydrophobization of the surfaces of particles so as to ease up the adhesion of these solid particles to the air bubbles and their conveyance up to the water surface [2].

The hypobaric flotation installation (Fig. 1) [3,4] comprises a flotation cell (1), a hydro aerator (2), which provides the depression necessary to release the dissolved air the lifting of foam in the separation tank (5) after being supplied with an influent, previously saturated in air by stirring it in the stirrer (8). In the separation tank (5), the column of mud (comprising the adhered solid particles) pushes the valve type ball of the discharging device with hydraulic closure (7); thus there is a continuous or intermittent discharge. The effluent accumulates at the basis of the cell and is discharged through the device no. 6. a part of the effluent is the recirculation water that is introduced

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into the hydro aerator (2). This one operates on the principle of the jet compressors that take a part of the released air from the circuit, it is emulsified in the water and then, it is re-introduced into the cell by the accelerator (3).

The hydro aerator is a device that operates in centrifugal field and uses Coanda effect: it involves the aspiration and dissolving a high amount of air into water, with the formation of very small air bubbles, phenomenon intensified by the foaming agent introduced into the hydro aerator.

The accumulation of the adhered solid particles into a foam layer shall flow into the overflow of the cell from where the separation tank is supplied (5).

The liquid column overcomes the weight of the ball in the hydraulic discharge device (7) and it is discharged as an adhered type product that is subjected to subsequent processes (drainage, biological treatment, etc.).

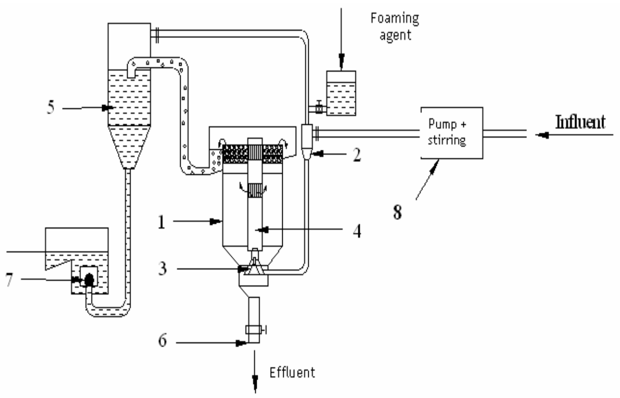

Fig. 1. Basic scheme of the flotation installation with hydro aerator. 1- Flotation cell, 2- Hydro aerator, 3- Accelerator, 4- Central adhesion tube, 5- Separation tank, 6- Discharging device, 7- Valve, 8- Centrifugal pump, 9- Conditioning device

❖ THE FLOWCHART OF TESTING

The laboratory installation was tested by taking into consideration the large numbers of variables; there has been developed a flowchart that is shown below.

I. Influent made of mechanical mixture comprising drinking water and mineral oil

1. Supplying the influent by centrifugal pump		*2. Supplying the influent by pressurization with compressed air*	
A	*- different content of pollutants (5,33mg/dm^3 H_2O, 10,66 mg/dm^3 H_2O, 26,65 mg/dm^3 H_2O) - constant supply pressure (0,2MPa)*	B	*- different content of pollutants (5,33mg/dm^3 H_2O, 10,66 mg/dm^3 H_2O, 26,65 mg/dm^3 H_2O) - constant supply pressure (0,2 MPa)*
C	*- constant content of pollutants (10,66 mg/dm^3 H_2O) - different supply pressure (0,10 MPa, 0,2MPa, 0,3 MPa)*	D	*- constant content of pollutants (10,66 mg/dm^3 H_2O) - different supply pressure (0,10 MPa, 0,2MPa, 0,3 MPa)*
E	*- constant content of pollutants (10,66 mg/dm^3 H_2O) - constant supply pressure (0,2MPa) - supply of different tensioactive substances (of Spumar type, P1, P2, P3)*	F	*- constant content of pollutants (10,66 mg/dm^3 H_2O) - constant supply pressure (0,2MPa) - supply of different tensioactive substances (P2, P3)*

II. Influent made of house waste waters sampled from the Cleaning Station Of House waste Waters of Petrosani town

G	*- constant content of pollutants - different supply pressure (0,10 MPa, 0,2MPa, 0,3 MPa)*
H	*- constant content of pollutants - constant supply pressure (0,2MPa) - supply of differnt tensioactive substances (P2, P3)*

For a higher accuracy, each test series was repeated 3-4 times.

1-Type of influent: Mechanical mixture of mineral oil and drinking water
2-Concentration of the pollutant (oil) in the influent: 10,66 cm^3/dm^3
3-Presence of tens active substance: Yes
4-Type of tens active substance: P_2 foaming agent;
5-Specific consumption of tens active substance: 0,033 cm^3/ dm^3
6-Pressure for supplying with influent the hydro-aerator: 0,2 MPa
7-Supplying the hydro-aerator: by pressurization with compressed air;

TEST CHART F_1

No. sample	Type sample	CCO -Cr [mgO$_2$/dm^3]	η cleaning [%]
1	I	153,5	52,90
	E	72,3	
2	I	153,5	52,44
	E	73,0	
3	I	153,5	52,57
	E	72,8	
Average cleaning output: 52,64%			

The test shown by the chart F_1 was optimized by the gradient method.

❖ THE GRADIENT METHOD TO FIND THE OPTIMUM DOMAIN FOR THE CLEANING OF INDUSTRIAL WASTE WATERS

The main idea is to find a situation conditioning period (x_1), supply pressure (x_2) and specific consumption of foaming agent (x_3) that provides the maximum cleaning level of the industrial waste waters (y). The optimization of this process has been made with the help of a matrix of changes for a three-factor experiment [7] (table 1). The base level was settled in relation to the observations drown from the above-said experiment, i.e.: the conditioning period (X_1) 30 min, supply pressure (X_2) 0.3 Mpa and specific consumption of foaming agent (X_3) 0,033 cm^3/dm^3.

Table 1. Comprises a synthesis of the experiments

Observations	Influence analysed for the variables (factors)			Cleaning output [%]		
	X_1 Conditioning period (min.)	X_2 Supply pressure (Mpa)	X_3 Specific consumption of foaming agent (cm^3/dm^3)	y_1	y_2	$Y_{average}$
0	1	2	3	4	5	6
1. Base level A_0 (X_1^0, X_2^0, X_3^0)	30	0,3	0,033	52,80	52,40	52,60
2. Unitary change S_i	10	0,05	0,0083			
3. Upper level ($X_i^+ = X_i^0 + S_i$)	30+10=40	0,3+0,05=0.35	0,033+0,0083=0,0413			
4. Lower level ($X_i^- = X_i^0 - S_i$)	30-10=20	0,3-0,05=0,25	0,033-0,0083= 0,0247			
5. Programming matrix Test 1 (point A_1) Test 2 (point A_2) Test 3 (point A_3) Test 4 (point A_4)	 - + - +	 - - + +	 + - - +	 48,02 48,32 53,36 50,03	 48,10 49,00 53,10 50,95	 48,06 48,66 53,23 50,49
6. Regression coefficients a_i	- 0,46	1,74	-0,84			
7. Unitary range $\Delta = a_i * S_i$	(-0,46)*30= -13,8	1,74* 0,2= 0,348	(-0,84)*0,033=0.027			
8. Regression coefficients (a_i) vs. estimation (Sa)	a_1 « Sa -0,14 « 0,026	a_2 » Sa 1,74 » 0,026	a_3 « Sa -0,84 « 0,026			
9. Base level A_0 (X_1^0, X_2^0, X_3^0)	20	0,35	0,0247	53,36	53,10	53,23
10. Unitary change S_i	15	0,05	0,0016			
11. Upper level ($X_i^+ = X_i^0 + S_i$)	20+15=35	0,35+0,05=0,4	0,024+0,0016= 0,0256			
12. Lower level ($X_i^- = X_i^0 - S_i$)	20-15=5	0,35-0,05=0,3	0,024-0,0016= 0,0224			
13. Programming matrix Test 1 (point A_1) Test 2 (point A_2) Test 3 (point A_3) Test 4 (point A_4)	 - + - +	 - - + +	 + - - +	 49,20 54,10 56,54 51,10	 50,48 53,98 56,54 51,02	 49,84 54,04 55,92 51,06
14. Regression coefficients a_i	- 0,167	0,775	2,264			
15. Unitary range $\Delta = a_i * S_i$	0,167*15= 2,5	0,775* 0,05= 0,038	0,0016*2,264= 0,0036			
16. Regression coefficients (a_i) vs. estimation (Sa)	a_1 » Sa 0,16 « 0,07	a_2 » Sa 0,775 » 0,07	a_3 » Sa 2,264 » 0,07			
17. The following stage towards the optimum point (B_1) $X_i^1 = X_1^0 + k\Delta_i$; (k =1/2)	30 - 0,5 * 2,5 =28.75	0,3+0,5*0,038 =0,32	0,033+0,5*0,0036 = 0,0348	57,64	57,82	57,73
18. The following stage towards the optimum point (B_2) $X_i^2 = X_1^1 + k\Delta_i$; (k =1/4)	28,75-0,5*1,25 =28.11	0,32+0,5*0,019 =0,33	0,0348+0,5*0,0018 = 0,0357	63,38	63,12	63,25
19. The following stage towards the optimum point (B_3) $X_i^3 = X_1^2 + k\Delta_i$; (k =1/8)	28,11-0,5*0,625 =27,79	0,33+0,5*0,01 =0,335	0,035+0,5*0,0009 = 0,03545	67,74	67,20	67,47
20. The following stage towards the optimum point (B_4) $X_i^4 = X_1^3 + k\Delta_i$; (k =1/16)	27,79 - 0,5*0,312 = 27,634	0,335+0,5*0,004 = 0,337	0,03545+0,5*0,0004 = 0,0356	71,62	71,84	71,73
21. The following stage towards the optimum point (B_5) $X_i^5 = X_1^4 + k\Delta_i$; (k =1/32)	27,634 - 0,5*0,156 = 27,556	0,337+0,5*0,002 = 0,338	0,0356+0,5*0,0002 = 0,0357	70,08	70,16	70,12
22. Check point $X_i^4 = X_1^3 + k\Delta_i$; (k =1/16) STOP OPTIM	27,79 - 0,5*0,312 = 27,634	0,335+0,5*0,004 = 0,337	0,03545+0,5*0,0004 = 0,0356	71,95	71,91	71,93

After optimizing, the cleaning output increased from an average value of 52.6% to 71.9%.

❖ THE DESIGN IF THE HYDRO AERATOR AND OF THE FLOTATION CELL AT INDUSTRIAL SCALE

This part intends to present the implementation of the results gained during laboratory tests at industrial scale by hydro dynamic similarity.

❖ THE DESIGN OF THE HYDRO AERATOR

The design of the industrial hydro aerator was made with the help of software using the criteria of hydrodynamic similarity so that the phenomena that occur in the laboratory should also replicate at industrial scale. In order to be able to implement the results of lab researches at industrial scale and to design a device able to dynamically replicate the processes occurring inside the laboratory model, there has been used the dimensional criterion M that describes the relation between the dynamic factors, geometric parameters and the volume charge Q. M criterion is expressed by the following equation:

$$M = (D_2 - D_1)\left(\frac{D_2^2 - D_1^2}{Q}\right)^3 \quad [s^3/m^2] \tag{1}$$

The follow rate gained by an industrial hydro aerator when attaining the same depression results by impasing the equalization condition of M criterion, i.e.:

$$Q' = \sqrt[3]{\left(D_{max}^2 - D^2\right)\frac{D_{max} - D}{M}} \tag{2}$$

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❖ THE DESIGN OF THE FLOTATION CELL

To design the flotation cell, there have been taken into consideration the overall sizes of the adhesion tube and of the acceleration chamber, the influent retention period and the supply flow rate.

The following sizes are known:

- the central adhesion tube:
  - height of the adhesion tube: 1.5 m
  - diameter of the adhesion tube: 0.296 m
- the acceleration chamber corresponding to the diameter of the central adhesion tube of 0.296 m; the radius of the upper part of the acceleration chamber is of 0.148 m to whom it corresponds a height of the coaxial area of 0.3:
  - height of the acceleration chamber: 1 m
  - internal radius of the basis of the acceleration chamber: 0.202 m
  - external radius of the basis of the acceleration chamber: 0.213 m.

We can conclude that the sum of the heights of the adhesion tube of the acceleration chamber is one of the overall sizes that have been taken into consideration:

$$h = h_t + h_c \text{ , m}$$

where: h_t – height of the central adhesion tube; h_c – height of the acceleration chamber.

$$h = 1.5 + 1 = 2.5 \text{ m}$$

The volume of the flotation vessel shall have to be able to take over a flow rate of 100 m^3/h for 2 minutes minimum and we shall consider a safety coefficient of k=1.5 for the safety of operations. It results that the volume of the flotation vessel is:

$$V = 1{,}5 * 2 * 60 * 0{,}0277 \approx 5 \text{ m}^3$$

If one considers that the vessel has a circular cross-section and the height of 2.5 m, the diameter of the flotation vessel:

$$A = V / h = 5 / 2{,}5 = 2 \text{ m}^2 \text{ ,}$$

That gives the diameter of the cell:

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \cdot 2}{\pi}} \approx 1{,}6 \text{ ,m} \qquad (3)$$

With the view to protecting people's health and the surrounding environment, the discharge into the sewerage system and into the natural receivers of industrial and house wastewaters with a high content of polluting substances is made in accordance with the requirements of the legislation in force, i.e. the Law of Waters no. 107/1996 and the Government Decision no. 188/2002 (NTPA 001, 002 /2002) [8,9].

In order to meet the requirements of the legislation in force on the discharge of waste waters, these waters should be subjected to a cleaning process.

❖ CONCLUSIONS

- One method used to clean up the waste waters is flotation that removes the fat particles, mineral oils and solid suspended particles from the waste waters.
- The laboratory installation used to clean up the waste waters comprises the following component parts: conditioning unit, hydro aerator, flotation hypobaric cell.
- The determination in the laboratory has followed the flow chart of the test plan.

In order to optimize the cleaning process by flotation means, there has been used the method of gradient.

- The experimental data gained from laboratory tests were used to design the main component parts of an industrial scale installation for cleaning by hypobaric flotation for a flow rate of 100 m^3/h.
- To be able to design an industrial scale aeration device there has been used a method that settles by the help of PC the main constructive elements, starting from the principles of hydrodynamic similarity.

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