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EXPERIMENTAL DETERMINATION OF ENERGY CONSUMED FOR CLEANING THE SELF-MAINTENANCE FILTERS

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Abstract: *Fluid filtration units with self-maintenance operation, due to their efficiency, have a widespread in industrial fields as chemical industry, food, wastewater, or agriculture. This paper is a stage in an extended program of applied research on the design and testing in prototype mode of new constructive solution of filters with operation in self-maintenance mode with applications especially in irrigation systems. The aims are to determine the optimal amount of fluid under pressure used for self-cleaning, the efficiency of the process and hence, the establishment of the energy required for this operation. The context is the determination of filters' efficiency. The filters which were analyzed are characterized by a filtering surface of 950 cm^3, a maximum flow 400 liter/ minute and a maximum working pressure 10 bars. The resulted minimum pressure for self-cleaning operation is 2 bar and the necessary flow is 140 l/minute.*
These filter units are complex electro-hydraulic structures where all the functional elements are correlated and closely related to the automation part. The pressure sensors, solenoid valves and PLC help the whole system to work in automatic control mode (automatic control theory). The correct fluid dimensioning of the elements that make up the self-cleaning device determines the efficiency of the filter. The theoretical results in fluid mechanics are recommended to be confirmed and corrected by experimental methods on stand.

Key words: *fluid dynamics, electro hydraulics, self-cleaning, automatic adjustment, sensory*

1. INTRODUCTION

Water resources management is an integrative concept for several sub-domains such as hydro, industrial waters, domestic waters, environment, irrigation, etc. An integrated perspective of water resources has economic, social, environmental, and technical-technological dimensions.

The field of agricultural production became agro-industrial with the evolutions and revolutions produced in the industrial environment. The techniques and technologies implemented so far have had as main purpose the facilitation of physical effort through so-called mechanization.

The spectacular evolutions produced in the last decades in the fields of informatics (hard and soft), sensors and data processing of chemistry and biochemistry or genetics, have started to be applied successfully and with spectacular effects in agricultural production. Thus appeared applications materialized in plant production farms whose level of automation and especially computerization successfully compete with the top applications in the industrial environment [1].

These results are the effect of an efficient collaboration and communication between specialists from seemingly different domains such as: agronomists, biologists, geneticists, plumbers, and computer scientists. Also, the climate changes felt in our country lead to the re-evaluation of the strategies in the field. This confirms the opportunity of this research project. In other words, if the objective needs of technology, for alignment with European standards and the pressure generated by climate change require action, then they should be considered and based on information as accurate and complete as possible so that the effects are the desired ones.

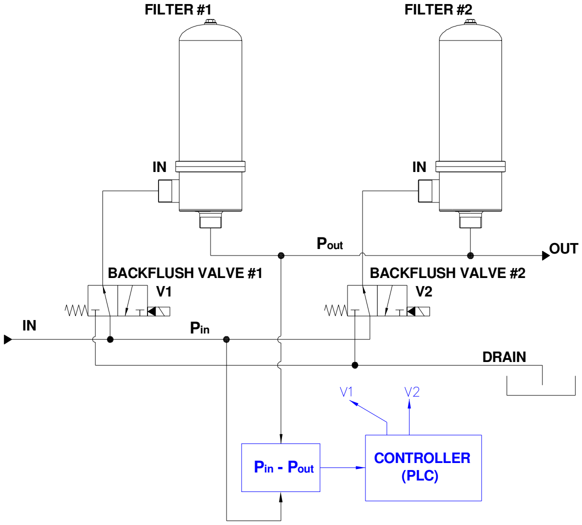
2. DESCRIPTION OF THE FILTRATION SYSTEM

Modern micro-irrigation systems can provide water and nutrients in precise quantities and at controlled frequencies directly in the root zone of the plant. In any system without proper filtration, pipes can build up in them, which can make the system less efficient.

Automatic self-cleaning filters come with many advantages, but perhaps the biggest of them is that they are low maintenance. This reason makes them as an excellent choice because they do not require operator intervention.

Another major benefit of industrial self-cleaning filters is that they clean themselves while the system is still running. Thus, the user saves money, energy and time. They also generally have a compact design that allows flexibility during installation.

The hydraulic diagram of the self-cleaning filter unit that is the object of the present study is presented in figure 1



. **Fig. 1**. Hydraulic diagram

Based on the diagram, the mode of operation can be described: the fluid to be filtered reaches the two filters that operate in parallel. The fluid is accessed through two solenoid valves, one for each filter. Normally the two filters work in parallel. The clogging (fouling) state is detected by a differential pressure transducer whose signal transmitted to a controller triggers a self-cleaning cycle.

At this point the V1 solenoid valve switches filter # 1 to self-cleaning mode and filter # 2 continues to filter and supply water to the system. Some of the filtered water is used to clean filter # 1. After a period, the V1 solenoid valve switches to the idle state and filter # 1 returns to the filtering mode. Then the PLC activates valve V2 and it passes filter # 2 to the self-cleaning state.

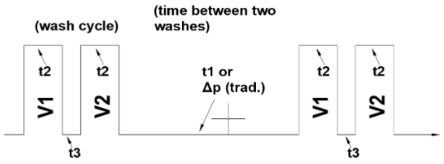


Fig. 2. Operating diagram of the filters

After a period, the V2 solenoid valve switches to the idle state and filter # 2 returns to the filtering mode.

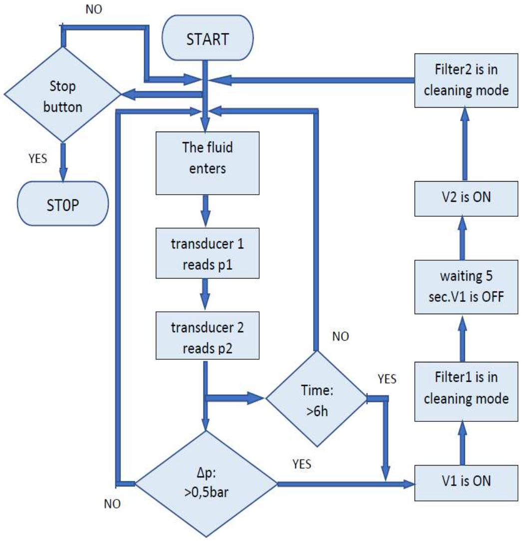


Fig. 3. Logical diagram of the filtration and self-cleaning process

Fig. 4. Filter stand ready for testing

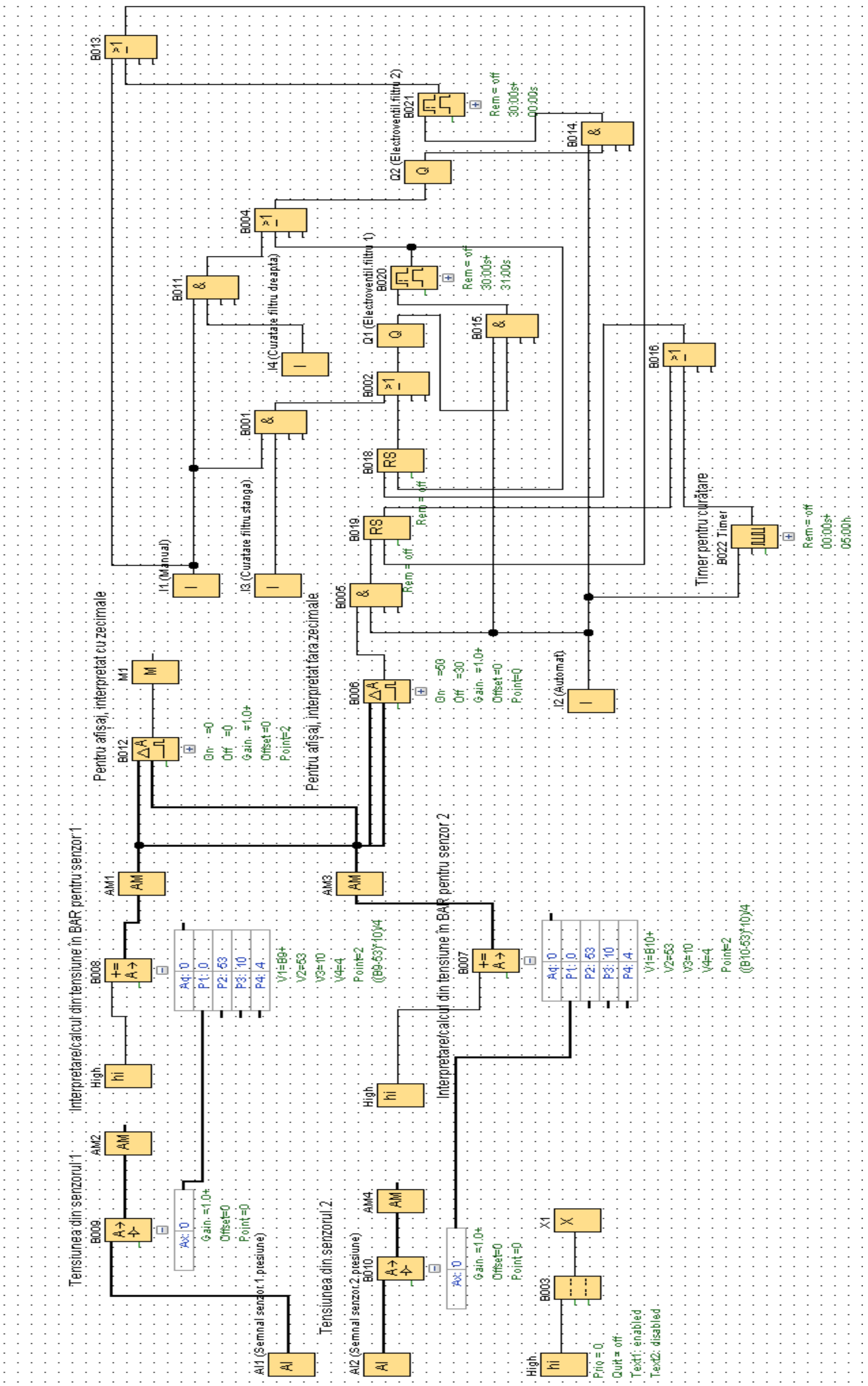


Fig. 5. Operating program for PLC

Furthermore, the two filters will operate in parallel until the differential pressure transducer announces the level of clogging that requires cleaning. The description of the filter operation is represented synthetically and suggestively in the diagram in figure 2. The next step was to develop the logical scheme. Here are included all the operation steps presented textually above. See figure 3.

A control unit and given acquisitions were designed and executed as shown in figure 4 in order to make functional the stand on which the operation of the filters will be verified as well as the quality of the self-cleaning process. Then the program for PLC was elaborated (figure 5).

The following tests were performed on the filter unit shown in figure 4. This is an original constructive solution and the tests presented in the paper, together with others, were performed to determine the functional performance.

3. THEORETICAL CONSIDERATIONS

Several variables influence the washing time of the filter surface. The time interval between two washes can be determined by reading the pressure difference between the inlet and outlet of the filter unit.

The wash time must be either the time during which the pressure difference between the internal and external surfaces of the filter surface decreased to the initial value from the beginning of the filtration. However, because not all particles accumulating on the filter surface can be washed, the pressure difference between the internal and external surfaces cannot be reduced to the initial value at the end of the washing processes; instead, it is slightly larger than the initial pressure difference.

Therefore, a parameter Pm is proposed, which is the ratio between the washed impurities and the impurities deposited on the filter surface. Thus, the end of the washing process is considered when the percentage of Pm particles has reached a reference level [5].

With these considerations will be determined the total mass of particles deposited on the filter surface with the formula:

$$M = QSPt \tag{1}$$

Where M is the total mass of particles deposited on the screen surface (kg); Q is the flow rate over the filter (m3 / s); S is the average concentration of impurities at the filter inlet (kg / m3); P is the percentage of particles larger than the diameter of the screen eye; and t is the filtering time (time). The total mass of washed particles over time t_p is:

$$M_p = Q_p S_p t_p \tag{2}$$

Where: M_p is the total mass of particles washed back from the filter (kg); Q_p is the backwash flow rate (m3 / s); S_p is the average sand concentration in the backwash hole (kg / m3); and t_p is the backwash time.

Based on the definition of wash time and the law of conservation of mass, the potential equation is:

$$M_p = P_m M \tag{3}$$

where P_m is the ratio of the washed particles to the particles deposited on the surface of the screen. By applying equations (1), (2) and (3), the following relation expressing the washing time can be established:

$$t_p = \frac{QS}{Q_p \times S_p} P P_m t \tag{4}$$

A mathematical expression of the pressure difference between the inlet and outlet of the filter will be of the form:

$$\Delta p_1 = \frac{\mu u L K_1 S_1^2 (1-\varepsilon)^2}{\varepsilon^3} \tag{5}$$

where L is the width of the filter discs (m); μ is the viscosity of water (Pa.s); u is the speed of the current (m / s); S1 is the area of a single particle (m2); ε is the porosity of the media; and K1 is an empirical coefficient, which is 5.0 when the porosity of the medium ε is between 0.3 and 0.5 [7].

To determine the maximum flow rate that can pass through the filter:

- the filtering capacity is defined as the size:

$$\boldsymbol{q = \alpha \cdot \frac{\Delta p}{\eta}; \left[\frac{m^3}{s \cdot m^2}\right]} \tag{6}$$

Where:

- α is a proportionality coefficient, which expresses the capacity of the fluid to pass through the surface unit of the filter, at a pressure difference of 1 Pa for a liquid having a viscosity:

$$\eta = 1\frac{N\cdot s}{m^2} \tag{7}$$

- Δ is the pressure drop on the filter [Pa];
- η is the dynamic viscosity coefficient $\left[\frac{N\cdot s}{m^2}\right]$, in water this coefficient is 1;

It follows that the maximum flow that can pass through the filter will be:

$$Q = q\cdot A \tag{8}$$

Where A is the cylindrical surface formed by the column of filter discs $\left[m^2\right]$.

Based on these theoretical considerations, it resulted that for a filtration capacity of 400 dm^3/min the designed filters must have a filtration surface of 950 cm^2.

Next, the flow regime through the washing nozzles is defined. These nozzles are positioned on four columns, spaced 8 mm apart and directed towards the filter discs.

The speed with which the fluid comes out through these nozzles is calculated with the formula:

$$v = \sqrt{\frac{2\cdot\Delta\cdot p}{\rho}} \tag{9}$$

And the flow through each nozzle is calculated with:

$$Q = v * \frac{\pi * d^2}{4} \tag{10}$$

Once the speed and flow of the fluid coming out of a washing nozzle are defined, the impact force on the impurities deposited on the filter discs can be determined:

$$\vec{F}_{L-P} = \rho Q v[(1-cos\alpha)\vec{\imath} - sin\alpha\vec{\jmath}] \tag{11}$$

For our case, the jet of fluid coming out of the nozzles acts perpendicular to the surface of the filter discs and for this situation α = π / 2.

The figure below (figure 6) suggests the effect of the fluid jet described above in mathematical format [6].

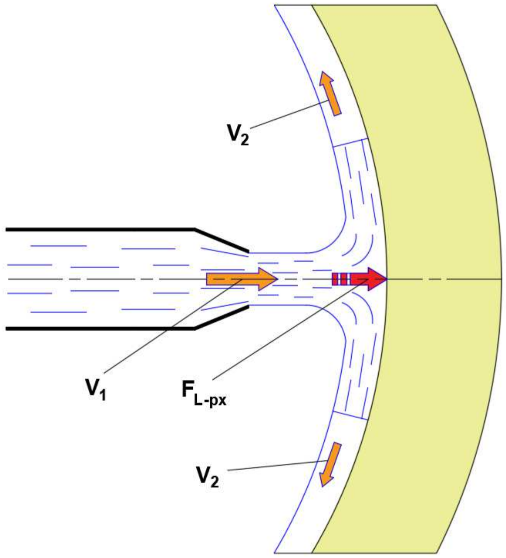


Fig. 6. The effect of the fluid jet on the filter surface

Now there are all the elements to be able to determine the impact force of the fluid jet coming out of the nozzles on the impurities deposited on the discs.

$$\boldsymbol{F_{L-px}} = \boldsymbol{\rho}\, Q\cdot \boldsymbol{v_1} \tag{12}$$

It can be also defined the power with which these fluid jets work:

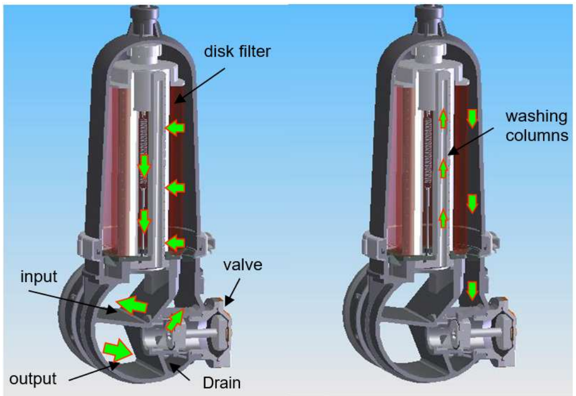
$$P = F_{L-Px}\cdot v_1 \tag{13}$$

These are the theoretical considerations that constituted the reference for the tests and measurements that will be presented in the next chapter.

4. EXPERIMENTAL DETERMINATION OF THE QUALITY OF THE SELF-CLEANING PROCESS

As it was highlighted, from a theoretical point of view, two hydraulic parameters have a major influence on the impact force. A high value of this force determines a good quality of filter cleaning as well as the duration of the self-cleaning process.

The filter units that operate in self-cleaning mode are built in the form of batteries of at least two filters. When the clogging level at which self-cleaning is required is reached, a filter continues to filter (even clogged) and the second filter switches to self-cleaning mode. Then after a certain time the roles are reversed: the cleaned filter returns to the circuit and the second filter is cleaned. The water circulation through the filters is shown in figure 7.



a.) b.)

Fig. 7. Fluid route through filter: a.) filtration mode, b.) self-cleaning mode

An experimental water velocity through the filter discs of 0.06 m / sec was established experimentally.

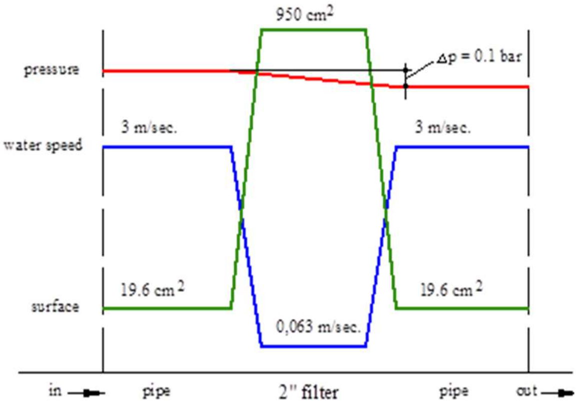


Fig. 8. Fluid pressure and speed as it passes through the filter

This low speed does not allow impurities to adhere to the surface of the filter discs and thus the self-cleaning operation is much easier. Figure 8 shows the flow rates at three points of the filter unit: inlet, at the crossing of the filter discs and at the outlet.

The figure below presents two columns of filter discs of the same filter unit. The disc column on the left went through a self-cleaning process.

Figure 9. The left column went through the self-cleaning operation

A series of tests were performed and the self-cleaning regime was modified according to the theoretical support of the test program.

Self-cleaning was performed for different pressure values. The self-cleaning pressure has been reduced to 1 bar. Thus, it was possible to see up to what value of the minimum pressure the self-cleaning is performed correctly.

Then the diameter of the nozzles changed (in the range 0.8….1.5 mm) and thus the washing flows were changed.

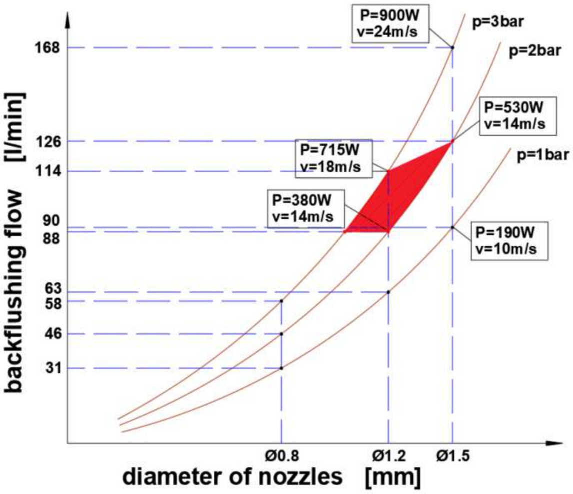


Figure 10. Optimal self-cleaning conditions for filters

For a better interpretation and evaluation, the results of the tests performed under the conditions presented above were concentrated in the form of a diagram presented in figure 10.
The optimal operating range for the self-cleaning operation is marked on the diagram shown and is defined by the following values: 2-3 bar pressure, nozzle diameter ø 1-1.5 mm.
The hydraulic power consumed for washing represents approximately 27% of the hydraulic power contained in the pressurized liquid that enters the filtration system.

5. CONCLUSIONS

These types of applications have incorporated a very high degree of automation and autonomy being able to operate indefinitely without human intervention.

The system contains pressure, clogging, pH, electro-chemical sensors, which provide information to a controller that, based on a dedicated program, filters and restores water properties.

In addition, the system self-diagnoses and self-maintains. Such water preparation systems have begun to be commonly used in agricultural and industrial applications

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DETERMINAREA EXPERIMENTALĂ A ENERGIEI CONSUMATE PENTRU CURĂȚAREA FILTRELOR DE AUTOÎNTREȚINERE

Rezumat: Unitățile de filtrare a fluidelor cu funcționare de autoîntreținere, datorită eficienței lor, au o răspândire în domenii industriale precum industria chimică, alimentară, ape uzate, sau agricultură. Această lucrare reprezintă o etapă într-un program extins de cercetare aplicată privind proiectarea și testarea în regim prototip a noii soluții constructive de filtre cu funcționare în regim de autoîntreținere cu aplicații în special în sistemele de irigare. Se urmărește determinarea cantității optime de fluid sub presiune utilizat pentru autocurățire, eficiența procesului și, prin urmare, stabilirea energiei necesare acestei operațiuni. Contextul este determinarea eficienței filtrelor. Filtrele analizate se caracterizează printr-o suprafață de filtrare de 950 cm^3, un debit maxim de 400 litri/minut și o presiune maximă de lucru de 10 bari. Presiunea minimă rezultată pentru operația de autocurățire este de 2 bari iar debitul necesar este de 140 l/minut. Aceste unități de filtrare sunt structuri electro-hidraulice complexe în care toate elementele funcționale sunt corelate şi strâns legate de partea de automatizare. Senzorii de presiune, supapele solenoide și PLC ajută întregul sistem să funcționeze în modul de control automat (teoria controlului automat). Dimensionarea corectă a elementelor care compun dispozitivul de autocurățire din punct de vedere al fluidului determină eficiența filtrului. Rezultatele teoretice în mecanica fluidelor se recomandă a fi confirmate și corectate prin metode experimentale pe stand.

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