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KOMAG INSTYTUT TECHNIKI GÓRNICZEJ

BADANIE, KONSTRUKCJA, WYTWARZANIE I EKSPLOATACJA UKŁADÓW HYDRAULICZNYCH

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BADANIE, KONSTRUKCJA, WYTWARZANIE I EKSPLOATACJA UKŁADÓW HYDRAULICZNYCH

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WPROWADZENIE

Prezentujemy Państwu kolejną monografię poświęconą badaniom, konstrukcji, wytwarzaniu i eksploatacji układów hydraulicznych. Jest ona owocem konferencji zorganizowanej przez Instytut Techniki Górniczej KOMAG w Gliwicach. W jej pięciu rozdziałach zawarto wyniki prac analitycznych, projektowych, badawczych i wdrożeniowych prowadzonych przez jednostki naukowe oraz przedsiębiorców, zarówno krajowych jak i zagranicznych.

W rozdziale pierwszym omówiono kierunki rozwoju układów hydraulicznych na podstawie analizy rynku techniki płynowej. Podkreślono, że na tle coraz większej globalizacji rynku europejskiego, istnieją możliwości konkurowania na nim firm z Polski.

W rozdziale drugim zaprezentowano innowacyjne rozwiązania układów hydraulicznych stosowanych w maszynach i urządzeniach dla górnictwa, w tym w sekcjach obudowy zmechanizowanej, lokomotywach oraz maszynach do drążenia szybów.

W rozdziale trzecim zaprezentowano techniki komputerowe stosowane w procesie projektowania i badań symulacyjnych układów hydraulicznych, autorstwa naukowców rumuńskich. Poruszono zagadnienie złożonej algorytmizacji oraz stosowania wirtualnych narzędzi do opracowywania coraz bardziej wydajnych układów hydrauliki i pneumatyki.

Wyniki prac badawczych poświęconych elementom układów hydraulicznych stanowią najbardziej obszerną, czwartą część monografii. Dotyczą one pomp, przekładni, napędów oraz przyrządów pomiarowych stosowanych w diagnostyce.

Rozdział piaty opisuje przykłady stosowania układów hydraulicznych w działalności przemysłowej oraz gospodarczej. Zaprezentowane wdrożenia świadczą o coraz szerszej skali ich zastosowań w górnictwie, energetyce, jak również w gospodarce rolnej.

Należy podkreślić, że tematyka monografii odzwierciedla poszczególne etapy cyklu życia produktu, począwszy od opracowania koncepcji, poprzez projektowanie, badania i wdrożenia, aż po utylizację i jest przykładem interdyscyplinarnego podejścia do opracowywania innowacyjnych rozwiązań układów hydraulicznych.

Redaktorzy naukowi monografii, jak i autorzy, współtwórcy rozdziałów mają nadzieję, że spotka się ona z szerokim zainteresowaniem środowiska naukowego, jak i przemysłowego.

Szczególne podziękowania chcielibyśmy złożyć recenzentom i redakcji technicznej za wkład w opracowanie niniejszej monografii.

prof. dr hab. inż. Adam Klich
dr inż. Antoni Kozieł
Redaktorzy naukowi monografii

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BADANIA NAD OPRACOWANIEM INNOWACYJNYCH URZĄDZEŃ DO FERTYGACJI

RESEARCH ON THE DEVELOPMENT OF INNOVATIVE FERTIGATION EQUIPMENT

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1. The importance of fertigation in irrigated agriculture [2]

Irrigation techniques have continuously evolved towards reducing the water consumption at plants (dripping, micro sprinkling) and higher valorization of water by reducing losses and association with other agriculture works (fertilization, herbiciding, etc.).

Modern agriculture cannot be conceived without irrigation, which is both a high performance technological sequence in the agro-technology of cultivated plants and the most important technical means for removing water shortage from the soil, forming the infrastructure of sustainable development.

Worldwide, the volume of freshwater (liquid and solid) is about 3.03% of the total volume, of which an amount of 23 thousand km^3/year can be captured and valorized, which is considered as insufficient for certain geographical areas.

Given the fact that irrigation uses a significant amount of freshwater, and plant needs are greater in dry periods, there shall be used other water sources as well (groundwater, drainage, urban wastewater and from livestock farms), that through their chemical composition meet the quality requirements of plants and environment.

To meet all water problems, The European Commission has considered to be necessary the development of new common policies, unified and coherent, which should take into account all the aspects, both those relating to human needs, and the ones that the existence of ecosystems depends on.

The fertigation equipment developed at our Institute includes the device for injection of fertilizing substance into the irrigation water, the container for preparation of fertilizing solution, the appliances for measurement and control of working parameters, the elements of hydraulic connection between the pieces of equipment. The injection device, of type double membrane displacement pump, will use as driving fluid the water taken from the supply pipe of the irrigation facility. The overpressure required for injection of primary solution in the same pipe will be achieved based on the principle of difference in surfaces between the drive chambers and the injection ones.

The equipment enables correlation between the technical elements of watering and the technical elements of fertilization, so that at the end of watering, once there is reached the depth of penetration of water into the area of prevalent development of the root system of plants, there is administered the whole amount of fertilizing solution necessary to plants, determined according to the stage of crop growth.

2. Calculation formulas and elements specific to implementation of the fertigation method in horticultural crops [2]

- ***Calculation of water volume required by the irrigation facility***

1. Calculation of the area to be irrigated, S (m^2):

$$S = L \times l, \quad (1)$$

where:

L- watering length of the installation, (m); l- watering width of the installation, given by the number of lines equipped with distribution devices (drip or micro sprinkler) and the spacing between the rows of the horticultural crop, (m).

2. Number of devices for distribution of the irrigation water, imposed by the spacing of planting for a certain horticultural crop along a row (in-row spacing):

$$N = n_l \, . l_d, \quad (2)$$

where:

n_l- the number of lines for distribution of irrigation water; l_d- optimal spacing between distribution devices, determined through tests performed under real operating conditions, (m).

3. Flow rate of the distribution device q_d, imposed by the horticultural crop irrigation technology (l/h); for the horticultural species of apple tree, the recommended flow rate of the dripper is 2 l/h

4. Flow rate of facility, Q_i (l/h):

$$Q_i = N \times q_d \, , \quad (3)$$

where

q_d- flow rate of the distribution device, (l/h);

5. Pluviometry of watering, p (mm/h):

$$p = Q_i : S \quad (4)$$

6. Irrigation quota, m (m^3/ha), imposed by the horticultural crop irrigation technology;

7. Duration of watering (irrigation time), T (h):

$$T = m / p \quad (5)$$

8. The volume of water to be administered, V (m^3):

$$V = m \times S \quad (6)$$

- ***Water consumption of the plant***:

$$MET = PET \times K_c, \text{ [mm]} \quad (7)$$

where

PET is potential evapotranspiration, in (mm); K_c - crop coefficient.

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- **Preparation of the primary solution**

The primary solution to be introduced into the irrigation system in order to produce the fertilizing solution can be:

- in the state of a solution made by the manufacturer, which is diluted;
- the solution is made by mixing the fertilizers with other chemicals.

Some systems inject the solution directly from cans, others from one, two or three containers.

Choosing the chemical solution to be used is dependent on a number of factors:

- the nutrient content and the proportion of each item; correspondence in milli-equivalents for the nutrient solution; the form of certain elements (nitrogen and ammoniacal nitrogen);
- other items which cause adverse effects (chlorine for certain plants);
- the desired effect in terms of pH value of the solution (the acid effect of various fertilizers).

- **Compatibility**

Certain chemicals must not be mixed in the tank, and others should not be injected simultaneously into the system, others depend on the quality of the water used (fertilizers containing phosphates should not be used in tanks containing calcium). This parameter is usually presented in tables provided by the manufacturer.

- **Solubility of chemical fertilizers commonly used in fertigation**

The solubility is the maximum amount of fertilizers that can be dissolved in a certain amount of water (100 liters). It depends on the fertilizer itself, the composition of each, the possibility of mixing chemical fertilizers, their temperature and pH.

- **Concentration of injected solution**

The injection equipment inserts the *primary solution* (of concentration C_m) in the irrigation water existing within the irrigation facility in order to produce the *fertilizing solution* (end use solution), of concentration C_s). The concentration of primary solution C_m is calculated by using the formula:

$$C_m = \frac{M}{V} \quad [g/l] \qquad (8)$$

where:

M - is the amount of solid fertilizers which is dissolved in a given volume, in (g);

V- volume of water in which fertilizers have been dissolved, in (l). this volume must be smaller than the water volume in which chemical fertillizers reach saturation.

A - dilution takes place at the injection point, depending on the flow (Q) of the irrigation facility and *the injection flow* (q) of the equipment injecting the primary solution.

- **Injection dosage (r)** and **dilution dosage (C_s)**

$$r = \frac{q[l/h]}{Q[l/h]} \qquad (9)$$

where r is expressed as per-cent (%) or per-mille (‰).

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Concentration of the end use solution (C_s) is determined by using the multi-line equation:

$$C_s[g/l] = C_m[g/l] \times r \quad (10)$$

$$C_s\,[\%\ volum] = C_m\,[\%\ volum] \times r$$

3. Monitoring the injection process performed by injection devices which are component of the fertigation equipment [2]

- ***Parameters of fertigation equipment***

If the injection is performed by means of a positive displacement pump, to calculate the pump flow **q**, there must be known the volume **Vs** of the primary solution injected per stroke and the pump frequency **f**. Because the volume V_s of the primary solution injected per stroke is a value imposed by design, pump frequency is calculated as follows:

$$f = \frac{n[strokes]}{t\ [min]} \quad (11)$$

where n is the number of strokes performed; t – time for performing the strokes.

Flow of the injection equipment is calculated as follows:

$$q\ [l/h] = 60 \times f\ [strokes\ /\ min] \times V_s \quad (12)$$

Flow of the irrigation facility is calculated as follows:

$$Q\ [l/h] = N \times q_i, \quad (13)$$

where: N is the number of distribution devices (drippers, sprinklers); q_i – average flow of distribution devices, [l/h].

In the case of using soluble solid fertilizers, where the primary solution is produced by the person who does the irrigation, time T_f is calculated by using the formula:

$$T_f[min] = \frac{60 \times M[g]}{Q\left[\frac{l}{h}\right] \times C_S\left[\frac{g}{l}\right]} \quad (14)$$

In the case of using fluid fertilizers (which represent the primary solution), time T_f is calculated by using the formula:

$$T_f[min] = \frac{60 \times M[g]}{Q\left[\frac{l}{h}\right] \times C_S[\%]} \quad (15)$$

The value of time T_f parameter must be smaller or equal to duration of watering T, to ensure environmental protection.

If the irrigation facility performs fertigation on the go, than fertigation time is equal to the irrigation time (duration of watering):

$$T_f = T \quad (16)$$

where:

T is irrigation time; T_f - fertigation time, in minutes.

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4. **Structure and working principle of the fertigation equipment** [1, 3, 4, 5]

The fertigation equipment, Fig. 1, is intended for fertigation of horticultural crops in protected areas (vegetables and flowers), respectively of field horticultural crops (vegetables, trees and fruit bushes).

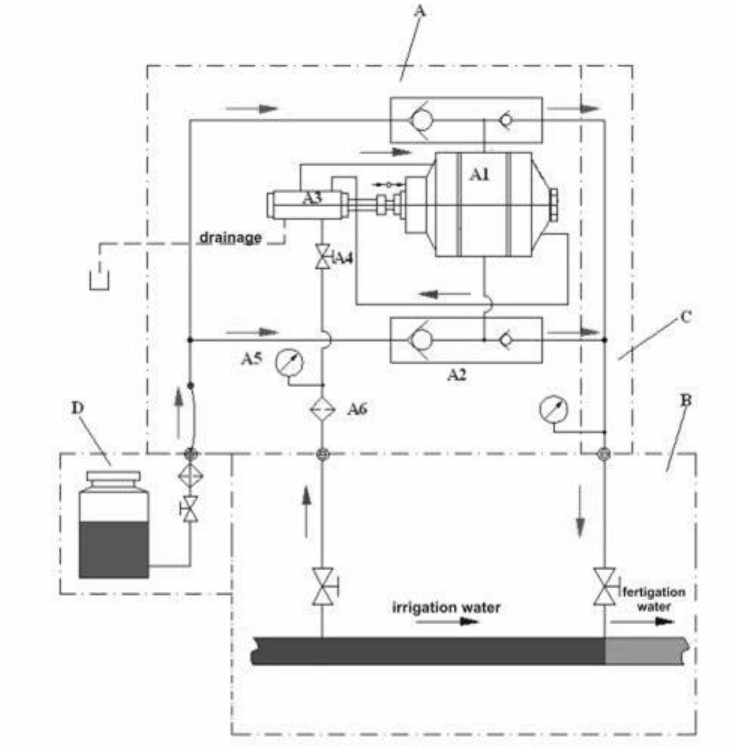

Fig.1. Structure of fertigation equipment

The injection device (A) is connected in parallel (bypass system) with the main circuit of the irrigation facility, by two quick couplings, in order to take over the water used as a drive fluid, respectively to perform injection of primary solution; this method of fitting does not introduces dissipation in hydraulic load inside the irrigation facility pipe.

The fertigation equipment [4] is structured as follows: A- equipment for continuous injection of primary solution; B-section connecting the fertigation equipment to the irrigation facility; C-system for monitoring the injection process; D-tank for fertilizer with related accessories.

In the configuration of this equipment there is a pipe section (B) with a diameter equal to the one of the main distribution pipe of the irrigation facility, an integral part of the irrigation facility; this section enables connecting the equipment to the hydraulic circuit of the irrigation facility.

Feeding the equipment with primary solution (provided in fluid state by the manufacturer or prepared out of solid chemical fertilizers which are water soluble) will be done from the container with fluid fertilizer (D).

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The principle of operation of the fertigation equipment [3, 5]

By opening the tap valves along the circuits, the pressurized fluid will pass, via one of the distributor ways (A3.1) (5/2 distributor - 5 ways, 2 positions), inside one of the drive chambers of the primary solution injector (hydraulic diaphragm amplifier), Fig. 2.

When the sliding valve of the distributor is in the position on the right, there is made a connection of the nipples P and A, feeding the left drive chamber A1 of the pump and the left chamber A3.2 of the hydraulic inverter, causing the displacement of the pump mobile assembly to the right, respectively the connection of the nipples B and Drainage, allowing water discharge from the right drive chamber of the pump and the right chamber of the inverter. During this stroke, from the left injection chamber, by compressing the associated membrane, there is performed injection of primary solution through the lower row of A2 valve block. The injection pressure places on the seat the left side valves –bottom row, the right side valves – upper row, and it opens the right side valve –bottom row, thus performing injection of the primary solution into the main hydraulic circuit of the irrigation facility.

At the same time, in the right side injection chamber negative pressure is created, causing the access of primary solution through the upper row of the valve block (the left side valve opened, the right side valve placed on the seat). When releasing the hole C1 within the inverter body, there is established connection with hydraulic distributor command, causing commutation of the sliding valve to the opposite position.

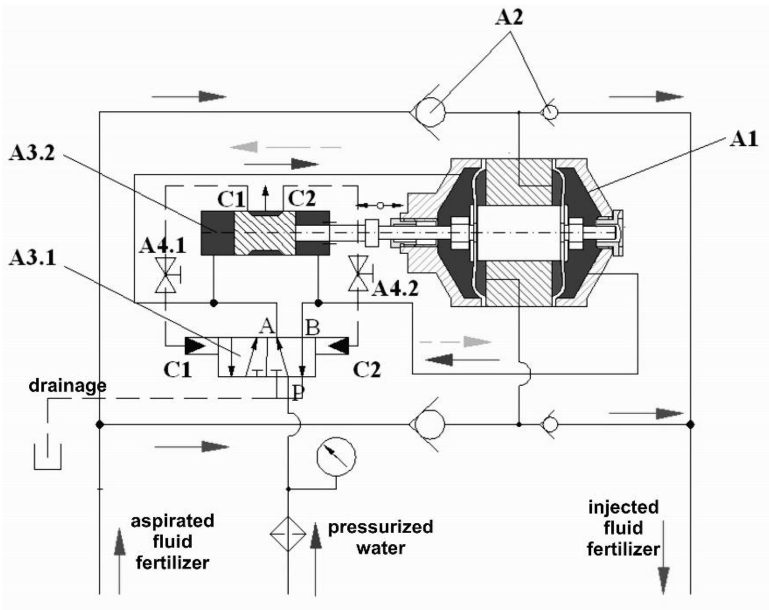

Fig. 2. The principle of operation of the dosing device

Figure 2 shows: A1-double membrane pump (hydraulic amplifier); A2- check valves unit of the injection circuit; A3.1- device for actuation of drive chambers; A3.2- hydraulic direction inverter; A4.1, A4.2- miniaturized tap valves, C1, C2 dive (pilot) chambers of the actuation distributor.

The double membrane pump [1], Fig. 3, can be assimilated to a hydraulic amplifier with two identical sections, separated by a central disc (4). Cloth insertion rubber membranes (3)

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have the shape of central holed discs. They are fastened between the outer lids of the pump (2, 6) and front sides of the disc on the outer contour, respectively between the front sides of the spool (5) and special design nuts on the inner contour. The membranes separate de drive chambers of the hydraulic amplifier (located on the outer side) and the injection chambers (located on the inner side).

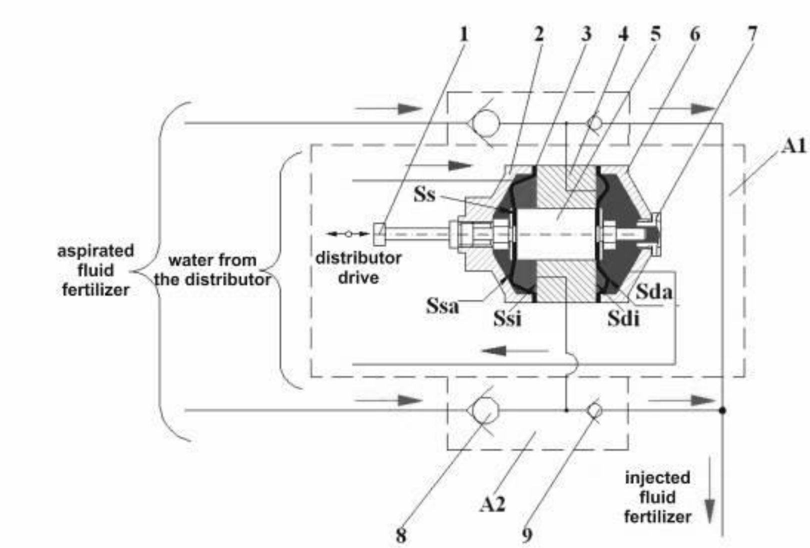

Fig. 3. Hydraulic diagram of the multiplier

1- axial drive rod, 2- left lid, 3- membrane, 4- case, 5- sliding valve, 6- right lid, 7- plug, 8- intake valve, 9- discharge valve

- Ssa, Sda – circular surfaces, left and right, on which water acts;

- Ssi, Sdi – circular surfaces, left and right, on which fluid fertilizer acts;

- Ss – circular surface of sliding valve.

The connection between the drive chambers and the outer hydraulic circuit for the working fluid is done through the holes in the lids, while the connection between the injection chambers and the outer circuit for intake-discharge of primary solution is done through the holes in the central disc [3, 5].

Reversing the movement of the pump mobile assembly is made using a hydraulic inverter, whose slide valve is integral with it. The difference between the active surfaces of the membranes, which are in contact with the drive fluid (the irrigation water) on the outside and with the primary solution on the inside, generates the overpressure needed to perform the injection process.

5. Results and discussion

When designing the injection device we started from the specific requirements of the mentioned horticultural crops (technical parameters of irrigation and fertigation) and also from the technical and functional characteristics of the irrigation facilities that the fertigation equipment works together with, as a single unit.

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For instance, for the horticultural crop of apple tree- sensitive varieties, located in the experimental plot of lands belonging to the Research Institute for Fruit Growing ICDP Piteşti-Mărăcineni, which is project partner, these parameters and characteristics are:

- The pipeline conveying water to the land plot (main pipeline)- Ø 100 mm;

- The pipeline connecting the fertigation pump to the main pipeline - Ø 60 mm;

- The irrigation hoses arranged on the rows of trees, on which the distribution devices (drippers or mini sprinklers) are located - Ø 16 mm;

- Spacing between the distribution devices on the irrigation hoses – 0.5 m

- Flow rate of distribution devices - 2 l/h;

- Lenght of the rows of trees (lenght of the irrigation hoses) - 160 m;

- Number of hoses (no. of rows) - 45;

- Fertilizing quota (primary solution administered during a irrigation sequence) - 100 ...150 l;

- Time of administering - 60 ...120 min.

From the calculations made it results that the injection device required flow q is 2.5 l /.

Technical and functional parameters of the injection device (diaphragm dosing pump), shown in Table 1, have been determined under laboratory conditions.

Technical and functional parameters of the dosing pump

Table 1

No.	p (bar)	f (ds/min)	Q_{inst} (l/h)	Q_{inst} (l/min)	q_{inj} (l/min)	r (%)	Ra-hid (%)
1.	2.0	70	384	6.4	2.2	2.2	45.8
2.	2.5	94	624	10.5	2.8	2.8	46.6
3.	3.0	112	798	13.2	3.4	3.4	48.5
4.	3.5	120	960	16.0	3.5	3.5	43.7
5.	4.0	170	1140	19.0	4.1	4.1	44.5
6.	4.5	192	1200	20.0	4.5	4.5	44.0

Where: p- water pressure in the watering system, bar; f- the frequency of the pump shaft, double strokes / min; Q_{inst}-flow in the system, l/h; l/min; q_{inj}-flow injected by the pump, l/min; r-injection rate-the fertilizer concentration in the irrigation water, (%); Ra-hid-hydraulic efficiency, (%).

The minimum pressure at which the pump starts operating is 0.5 bar, and the maximum working pressure is 8 bar.

Hydraulic efficiency of the pump, regarded as the ratio of the volume of injected fertilizing solution V_{inj} and the volume of water consumed in the operation of the pump V_m, $\frac{V_{inj}}{V_m} \cdot 100$, (%), is determined by hydraulic parameters of the water in the drive chambers and concentration of the fertilizing solution.

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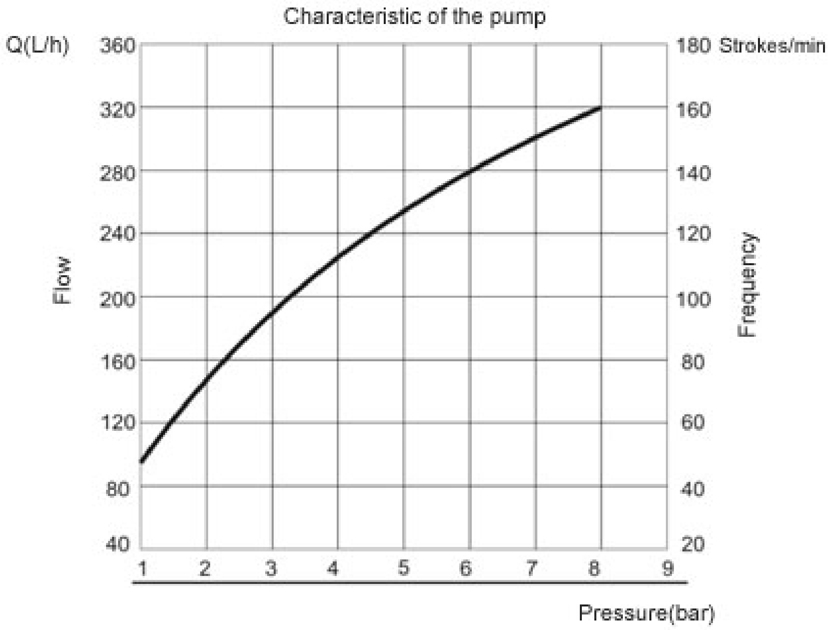

Fig. 4 Characteristic of the dosing pump

The pressure up to which the pump operates with high efficiency is 3.0 bar, hydraulic efficiency being 48.5 %, comparable to the hydraulic efficiency of dosing pumps available worldwide.

Figure 4 above shows the characteristic of the dosing pump.

Currently, at the Institute INOE 2000-IHP Bucharest there has been performed design and partial development of an innovative injection device with internal command, with hydraulic drive of the sliding valve of the distributor and reversing the direction of travel at stroke ends of the mobile assembly of the injector.

The fertigation equipment will be tested on fertigating horticultural crops in protected areas, trees and fruit bushes.

6. Conclusions

- Injection of fertilizers can be done in any point of the irrigation arrangement, the drive fluid being the irrigation water itself;
- Working pressures can be in the range 0.5 – 8 bar;
- To increase pump efficiency it is recommended to install several throttle devices (tap valves, diaphragms) between the connection points of the injection device to the irrigation facility;
- The water discharged by the pump will be distributed across the crop by means of drippers or perforated tubes.

The irrigation facility may be of the type: dripper, perforated tubes, or micro sprinkler installation.

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