Fertilizer Injection Device

PhD. Eng. **Gheorghe SOVAIALA**[1], Dipl.Eng. **Sava ANGHEL**[1], PhD. Eng. **Gabriela MATACHE**[1], Dipl. Eng. **Alina POPESCU**[1], PhD. Eng. **Petru CARLESCU**[2], PhD. Eng. **Nicolae TANASESCU**[3]

[1]INOE 2000-IHP Bucharest; sovaiala.ihp@fluidas.ro

[2]USAMV Iasi; pcarlescu@yahoo.com

[3]ICDP Pitesti-Maracineni; nicolae.tanasescu@yahoo.com

Abstract: *The fertilizer injection device is a component of the equipment for fertigation of horticultural crops (the main vegetable species cultivated in protected areas, and respectively tree species and shrubs) used at works in aggregate with drip irrigation and micro sprinkling systems.*
The injection device (type double diaphragm pump with hydraulic control) developed under the PN-II-PT-PCCA-2013-4-0114 –Contract no. 158/2014 in Experimental Model phase, offers a number of advantages compared to products of prestigious companies in the field such as VERDER AIR, DEBEM, TUV, TAPFLO, namely [4, 5]:

- It uses as working (driving) fluid the irrigation water, taken from the same pipe in which the primary solution is injected, which combined with the irrigation water forms the fertilizing solution;

- It does not require electricity or compressed air, which ensures operating autonomy in any spot of the arrangement for irrigation;

- The injection pressure is achieved on the principle of difference between the active surfaces of drive chambers and injection chambers, and it can be determined very precisely according to the hydraulic parameters of the irrigation facility which it works in an aggregate with, early since the product design stage ; the primary substance flow can be adjusted within wide limits, by changing the flow supplying the drive chambers, thus modifying the frequency of the pump central shaft (joint with the membranes that delimit the drive from injection chambers);

- It shall be installed in parallel with the main circuit of the irrigation facility (bypass system) through two quick couplings for taking over the water used as the driving fluid, and respectively for injecting the primary solution; this mounting system does not introduce pressure losses in the irrigation facility pipe.

Keywords: *Injection device, fertigation, primary solution*

1. Introduction

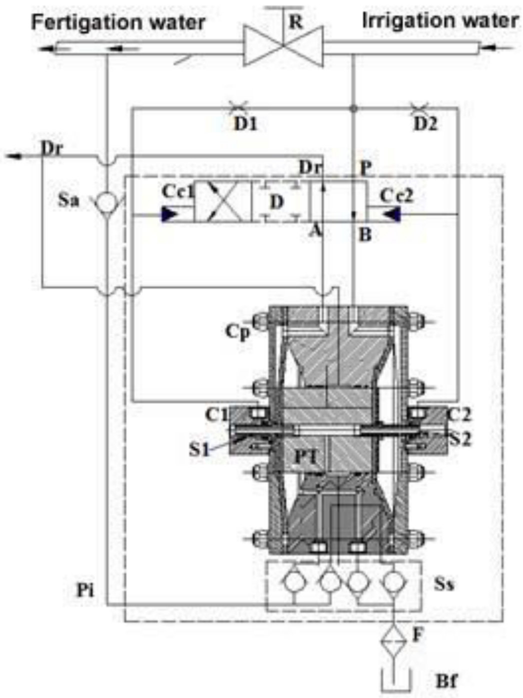

Fig. 1. Schematic diagram of the fertigation equipment

The fertigation equipment is structured as shown in Fig.1 above.
It includes the device for injecting the fertilizing substance into the irrigation water, consisting of the dosing pump *Pd*, the hydraulically actuated directional control valve *D* and the block of primary solution inlet/discharge valves *Ss*, the container for preparing the fertilizing solution *Bf*, the equipment for measurement and adjustment of working parameters (*D1* and *D2*- throttles, *Sa*- return valve, *R*- tap valve), the hydraulic connection elements between pieces of equipment [2].

2. Description of the injection device

The injection device is of type double positive displacement pump with diaphragms [1], [4], [5], with hydraulic control (commutation of the directional control valve is hydraulically performed).
It is mounted in a hydraulic circuit which is parallel with the supply (main) circuit of the irrigation facility (by-pass). Between the points of connecting the injection device to the irrigation facility there is mounted the tap valve *R*, acting as an adjustable diaphragm, with which there is created pressure drop downstream of the location point, thus facilitating the injection process (this increases, in a wide adjustment range, the pressure difference Δp between connection points).
The device uses water taken from the supply pipe of irrigation facility as driving fluid, the overpressure necessary to inject the primary solution in the same pipe being created on the principle of surface difference between the drive chambers and the injection chambers, respectively through tap valve *R*.
The functioning of this injection device does not imply the existence of electricity or compressed air, which ensures operating autonomy in any spot of the arrangement for irrigation. The design, technical and functional parameters can be set very accurately, from the product design phase, depending on the hydraulic parameters (pressure, flow rate, configuration and sizes of the supply and distribution network) of the irrigation facility which it works in aggregate with and the technical elements of fertigation (the watering quota administered by use of the irrigation facility, the features of injected primary solution: chemical composition, content in chemical elements, solubility and compatibility of chemical fertilizers used in the preparation of primary solution, density, concentration, electrical conductivity, acidity, water quality, injection dosage and dilution dosage).
Primary substance flow can be adjusted within very wide limits, by changing the feed rate of the drive chambers, thus modifying the frequency of the pump central shaft (joint with the membranes that delimit drive chambers from injection chambers).
The double positive displacement pump with diaphragms [6], Figure 2, can be assimilated to a hydraulic amplifier with two identical sections, separated by a central disc (pump body) *1*. The rubber membranes with cloth insertion (180) x20 -3x2.5 are in shape of discs with center hole. They are fixed between external covers of pump *2* and front sides of the central disc on outer contour, respectively front sides of the piston *4* and flanges *8* on the inner contour. The membranes separate drive chambers of hydraulic amplifier (located on the outside) from injection chambers (located on the inside).

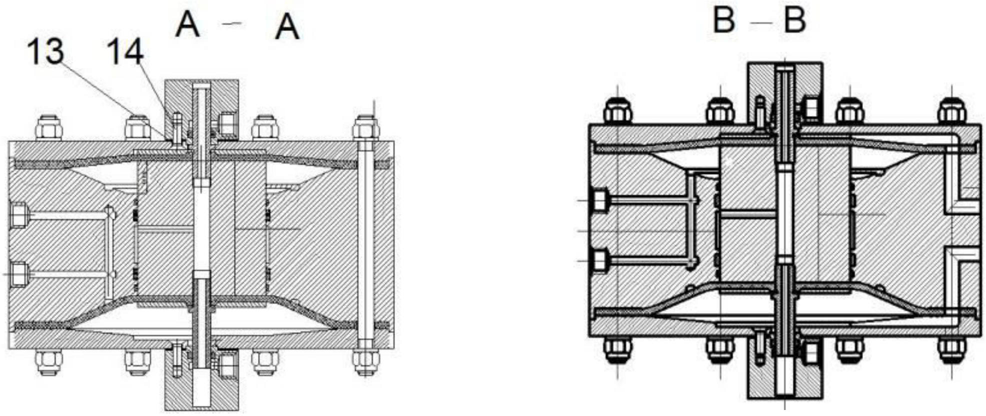

Fig. 2. Double positive displacement pump with diaphragm

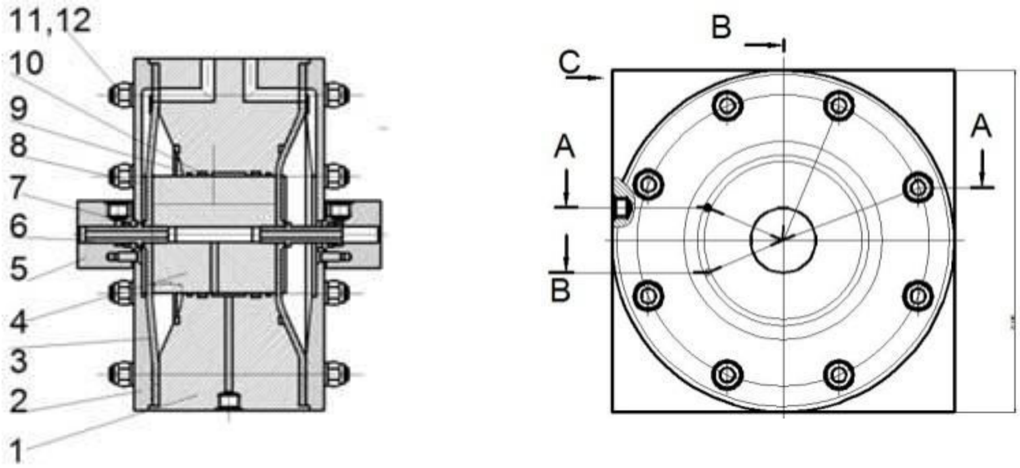

Fig. 2. Double positive displacement pump with diaphragm *(continued)*

The connection between drive chambers and exterior hydraulic circuit of the working fluid is accomplished through the passage holes in the covers and central disc, and the connection between injection chambers and exterior circuit of primary solution inlet-discharge is accomplished through the holes in the central disc.
The novelty of the technical solution taken up when developing the injection device consists in the directional control valve actuation, which is done by taking over hydraulic signals at the stroke ends of the pump mobile assembly, and also in the constructive manner adopted for the slide valve of the directional control valve, so that to meet the fertigation process requirements: quick switching; in the switching phase it should not generate pressure drop in the system, leading to blockage of the pump mobile assembly; once switched, there should exist forces to maintain it in position.

The hydraulic directional control valve

To control the travel direction of the mobile assembly of the injection device there is used a directional control valve supplied with water under pressure from the irrigation pipe upstream of the tap valve *R*, which it distributes alternately in the two drive chamber. Thus injection chambers increase or decrease in volume, sucking the primary solution from container *Bf* and discharging it through the branch with return valve *Sa* in the same irrigation pipe, downstream of the tap valve *R*, at a higher pressure than the one inside the pipe [6].
Actuation of the directional control valve occurs by sensing the stroke ends of the mobile assembly with membranes, by means of some slide valves, which open the way of directional control valve commands to an external drain *Dr*. Thus there is ensured the pressure drop on commands, so safe operation. Contact with the outside is done through the hole in the slide valve and the holes in the central piston, which regardless of the position it occupies, connects with the outside.
Control pressure is brought on the pistons ends of the distributor slide valve through two nozzles (throttles) *D1* and *D2* from pressure circuit *P*. These nozzles allow separation of the two control circuits, balancing of the distributor slide valve after its actuation and maintaining of the slide valve in position until receiving a new command.
The directional control valve, fig. 3, is a structure consisting of a body *1*, in which there is mounted an assembly comprising the slide valve *5* and two threaded bushings *2*, in which the slide valve pistons *8* delimit the two drive chambers. In the central area of the slide valve there are mounted symmetrically two valves, which by their displacement close or open paths from pressure port P to the consumer ports A or B, respectively to the drive chambers of the slide valve. At the same time connections are created between ports A or B and the output port T (*Dr*).
The valves are mounted on the slide valve so that in the central position they completely close the port P (positive coverage).

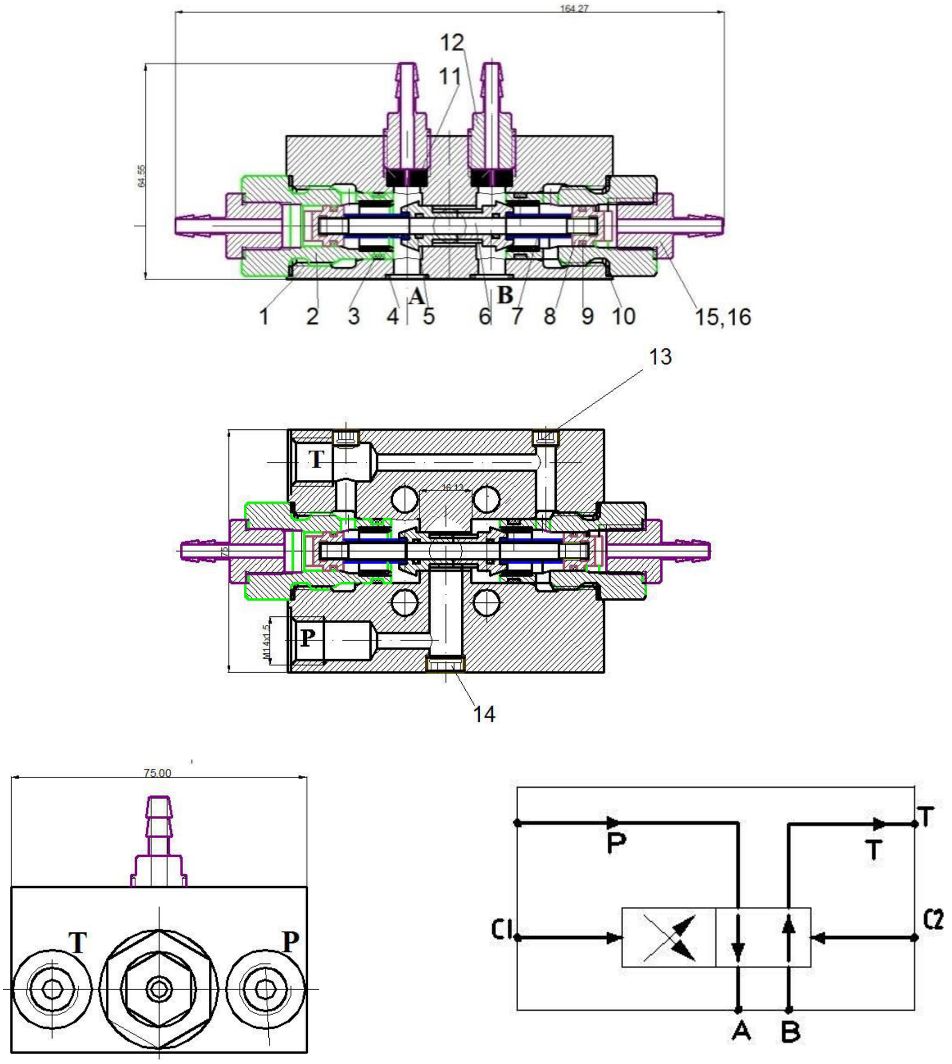

Fig. 3. Directional control valve

Under the action of pressure, the mobile assembly of the directional control valve is unbalanced, because the closing surface on the seat ϕD is larger than the closing surface type slide valve ϕd – see schematic diagram of the directional control valve, Figure 4. This creates a force that maintains in position the slide valve until it gets unbalanced as a result of pressure drop in the control chamber, by opening the paths at the stroke ends of the pump mobile assembly.

By moving to the stroke end, the slide valve of the pump sets the connection between the drive chambers of the directional control valve and the outside, through the port in the piston and pump body to *Dr*.

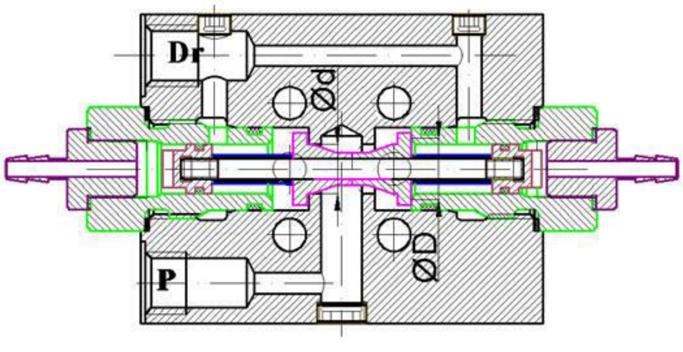

Fig. 4. Schematic diagram of the directional control valve

At the end of the slide valve stroke (e.g. the extreme right position) the right valve seals frontally on a seat *ϕD*, and the left valve on the cylindrical surface, at contact with the directional control valve body *ϕd*. Due to the difference between the surfaces *ϕd* and *ϕD*, pressurized water in the pressure circuit *P* generates a force that opposes switching of directional control valve:

$$\phi D > \phi d;\ AD > Ad;\ \text{so } FD > FD$$

where: D, d are diameters of the sections which water pressure is acting on; A_D, A_d - areas of the two sections; F_D and F_d - forces acting on the valves' assembly; $F = A \cdot p$, p- water pressure, A- area.
In this position of the slide valve, there are established the next paths: from *P* to the pump drive chamber *B*, respectively from the drive chamber *A* to the drainage *Dr*.
At switching, by pressure drop, there occurs unbalancing of forces:

$$F_D < F_d + F_{ccd},$$

where F_{ccd} is the force produced by pressure on the extremity of the control piston which is no longer balanced.
The control chambers of hydraulic directional control valve are connected by nozzles (throttles) *D1* and *D2* to the pressure circuit *P* and the control slide valves of the pump, Figure 5. When the pump mobile assembly reaches the stroke end, the slide valve in question opens the path to the outside, causing pressure drop in the control circuit, which unbalances pressure forces exerted on the distributor slide valve, and as a result causes switching of the later.
In the switched position, through nozzles *D1* and *D2*, pressure in the control chambers is balanced, and due to the differences in surface between *ϕD* and *ϕd*, there occurs a force that maintains the slide valve assembly on actuated position.

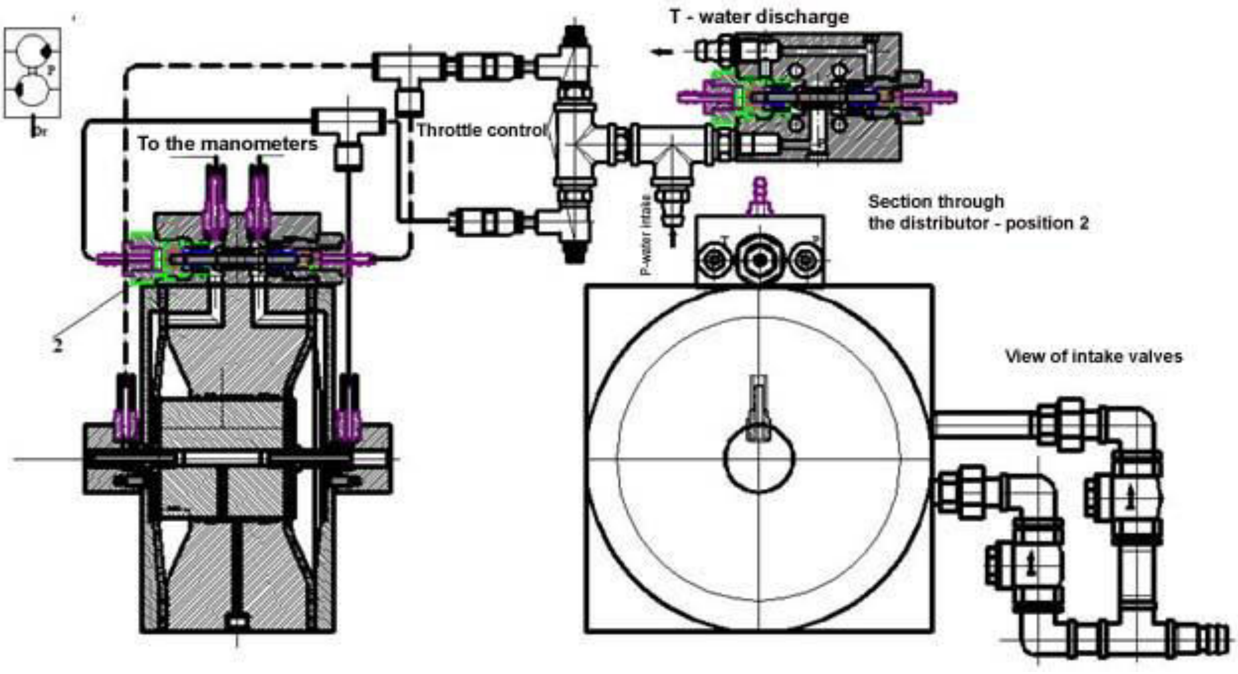

Fig. 5. Schematic diagram - Injection Device

The block of primary solution inlet /discharge valves
The block of primary solution inlet /discharge valves, Figure 6, consists of four needle type check valves and the related connection items.

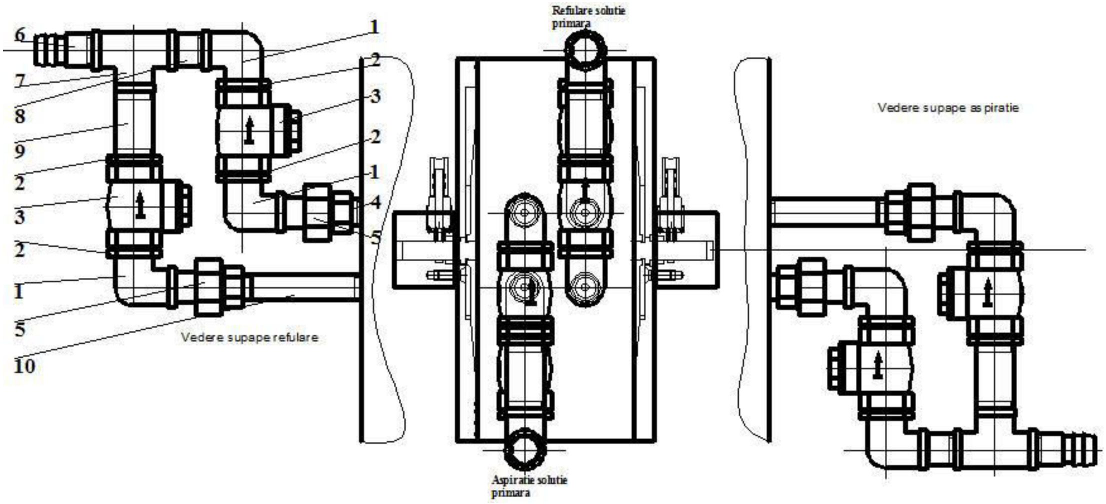

Fig. 6. The block of the primary solution inlet /discharge valves

The valves are arranged in two parallel planes, to each chamber being attached an inlet valve and a discharge valve, Figure 7. The inlet valves are connected to the branch *Ti*, by which the primary solution sucked from container *Bf* (Fig. 1) reaches alternately the two chambers, while the discharge valves are connected to the branch *Pi*, by which the primary solution is injected into the main pipe of the irrigation facility [6].

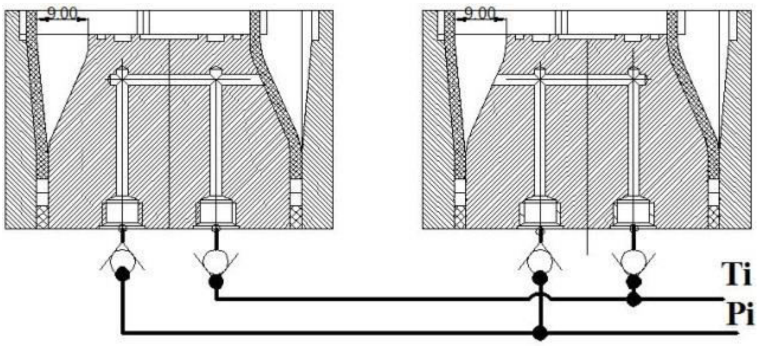

Fig. 7. Mounting scheme of the primary solution inlet /discharge valves

Ti-branch of primary solution intake valves;
Pi-branch of primary solution discharge valves.

The primary solution intake/discharge process takes place continuously in both directions of pump mobile assembly displacement, by varying continuously the volume of drive chambers and the volume of primary solution inlet/discharge chambers. Water inlet in one of the drive chamber determines its volume to increase, and respectively causes decrease in volume of the primary solution inlet/discharge chamber from which it is separated by the membrane, generating injection; at the same time the opposite drive chamber decreases its volume, water (after it played the role of driving fluid) being discharged through the drainage to the outside, and in the inlet / discharge chamber, by increasing volume, the primary solution intake process takes place. Depending on whether pressure or depression exists in the inlet/ discharge chambers, needles of valves component of the hydraulic axle are on seat or spun off. It should be mentioned that needle type valves have preferential installation position, so that, disengaged, the needle be in contact with the seat.
The injection device developed in EM phase is shown in Figure 8.

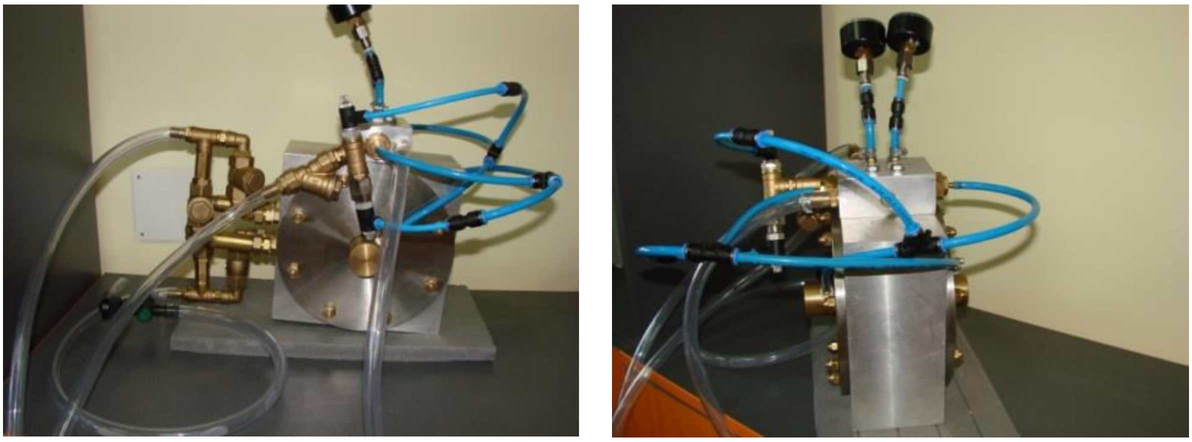

Fig. 8. Injection device - EM phase

3. Elements of calculus specific to fertigation [2]

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

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

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

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):

$$N = n_l \cdot l_d, \qquad (2)$$

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 the facility, Q_i (l/h):

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

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

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

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

6. Irrigation quota, m (m^3/ha), imposed by the horticultural crop irrigation technology;
7. Duration of watering (irrigation time), T (h):

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

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

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

- ***Water consumption of the facility***:

$$MET = PET \times K_c,\ [mm] \qquad (7)$$

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

- **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;
- 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 milliequivalents 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:

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

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)**

$$r = \frac{q[l/h]}{Q[l/h]} \tag{9}$$

where r is expressed as per-cent (%) or per-mille (‰).
Concentration of the end use solution (C_s) is determined by using the multi-line equation:

$$C_s[g/l] = C_m[g/l] \text{ x } r \tag{10}$$

$$C_s \text{ [\% volum]} = C_m \text{ [\% volum] x } r$$

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

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:

$$f = \frac{n[\text{strokes}]}{t\ [\text{min}]} \tag{11}$$

where n is the number of strokes performed; t – time for performing the strokes.
Flow of the injection equipment is calculated as follows:

$$q\ [\text{l/h}] = 60 \times f\ [\text{strokes / min}]\ \text{x}V_s \tag{12}$$

Flow of the irrigation facility is calculated as follows:

$$Q\ [\text{l/h}] = N \times q_i, \tag{13}$$

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 performs the irrigation, time T_f is calculated by using the formula:

$$T_f[\text{min}] = \frac{60 \text{ X } M[\text{g}]}{Q\left[\frac{1}{h}\right] \text{X } C_S\left[\frac{g}{l}\right]} \tag{14}$$

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

$$T_f[\text{min}] = \frac{60 \text{ X } M[\text{g}]}{Q\left[\frac{1}{h}\right] \text{X } C_S[\%]} \tag{15}$$

The value of T_f time 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):

$$T_f = T \tag{16}$$

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

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 features of the irrigation facilities that the fertigation equipment works together with as a single unit [3].
For instance, for the horticultural crop of apple tree- sensitive varieties, located on the experimental plot belonging to the Research Institute for Fruit Growing ICDP Piteşti-Mărăcineni, which is project partner, these parameters and features 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 along the irrigation hoses – 0.5 m
- Flow rate of distribution devices - 2 l/h;
- Length of the rows of trees (length 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.

A simulation of fertilizing solution distribution in a drip irrigation facility with the above mentioned technical and functional features has been developed by using ANSYS Fluent software and presented in HIDRAULICA journal issue 4/2015 [7].

6. Conclusions

- Injection of fertilizers can be done in any point of the irrigation arrangement, the drive fluid being the irrigation water itself;
- 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 irrigation facility may be of the type: dripper, perforated tubes, or micro sprinkler installation;
- From calculations it results that the flow q required by the injection device is 2.5 l /min;
- Working pressures can be in the range 0.5 – 3 bar (imposed by working pressure of distribution devices in the structure of the irrigation facility).

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