THE EFFICIENT USE OF WATER AND FERTILIZER RESOURCES IN A FERTIGATION PLANT

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ABSTRACT

This paper presents a simulation of a fertigation plant used in fruit growing with the purpose of studying the distribution of fertilizer over the entire plant. Increasing soil fertility in current intensive farming requires the use of modern solutions for the application of fertilizers along with the irrigation water (fertigation) in order to preserve water resources and prevent loss of fertilizing substance. The method used is based on mathematical models which have successfully addressed to simulate fluid flow in pipelines. The CFD (Computational Fluid Dynamics) simulation of water flow in the fertigation plant was considered turbulent, and the model applied k-ε. The fertigation plant used in simulation has 20 pipes with 800 droppers, and the inner diameter of a dropper is 0.8 mm. The diffusion of fertilizing solution in the irrigation water is difficult to monitor because of extremely low levels of concentration and variation depending on pressure along the network of pipelines. The CFD simulation was based on the assumption that the fertilizer is in the form of solid spherical grains with a diameter of 100 μm, and this fertilizer does not chemically interact with water. In this way there is provided hydraulic conveyance of particles from the main irrigation pipe to the dropper. The simulation results are presented in the shape of velocity fields and respectively as a trajectory of the fertilizer particles in the fertigation plant. By analyzing the trajectory and the manner in which the fertilizer particles disperse at the level of those 800 droppers there has been found unevenness of distribution. Thus a rate of 15% of the fertigation pipes has fertilizer at all 40 droppers. The rest of pipes have a lesser or greater proportion of droppers receiving fertilizer. Moreover, the distribution of fertilizer particles is made unevenly in the droppers in the first half of the plant compared to the last half.

The advantage of a three-dimensional simulation of water flow and movement of fertilizer particles is that it provides an overview as close as possible to the real fertigation process taking place in a grove of fruit tree.

Keywords: drip irrigation, water resource, fertigation, simulation

INTRODUCTION

Our planet's freshwater resources are increasingly more exploited; meanwhile consumption of fresh water in agriculture is rising because of extension of the agricultural land areas and increasing exploitation of these areas. Soil is the main source of mineral nutrients and water for plants, its capacity to ensure basic nutrients necessary for plants varies depending on fertility levels. Agricultural efficiency could rise with a better management of fertilization, better weed and disease control, and mainly with economic and efficient water consumption. Drip irrigation distributes water slowly, dropwise, near plant roots, preserving water resources. This irrigation method has been applied since 1860 in Germany when researchers from there began experiments using underground pipes made from clay to create a combination of irrigation and drainage system. Research has evolved and in 1920 there was applied a system of perforated tubes made from PVC and polyethylene to accumulate and distribute water. Utilization of a plastic dropper in the drip plant has been developed in Israel; in this one, instead of using small holes in the watering pipe which jammed easily, water was distributed by larger channels at a constant flow. Applying fertilizer under the form of solution in irigation water -*fertigation*- uses drip fertigation plants. In time, the dripping lines have been developed with a wide range of droppers according to the plants' needs of water and fertilizer. [1].

In past, studies on the distribution of water in irrigation plants have been developed through analytical methods, starting from known relations in hydrotechnics used to the calculation of high atmospheric and overpressure channels and pipe networks [2]. In present times these calculations are made by using high performance calculation techniques taking into account functional considerations, land slope, soil characteristics, type of the dropper being used, spatial dimension, and available pressure. Distribution of primary fertilization solution in the irrigation water and distribution of final solution in the fertigation plant has been less studied in the specialized literature. In this paper a CFD (*C*omputational *F*luid *D*ynamics) simulation has been developed to determine distribution of the fertilizing solution, through implementation of a dosing pump in the fertigation system which uses irrigation water as a source of functional energy. The DPM model (*D*iscrete *P*hase *M*odel) has been used in the CFD simulation to track the trajectory of fertilizer particles in the drip fertigation plant with droppers. The paper assumes that the fertilizer is solid in the form of spherical granules with diameter of 100 μm and it does not chemically interact with water. This method enables a hydraulic particle transfer from the main irrigation pipe to the dropper. The concentration and distribution of fertilizer granules and also the velocity field inside the fertigation plant is obtained by CFD simulation considering the k-ε turbulent flow model.

MATERIALS AND METHODS

The fertigation plant used in watering and distribution process modeling is shown in Figure 1. The novelty element of this plant is the fertilizer dosing pump which in order to function uses irrigation water energy itself instead of an external source of power. This is a great advantage in the open field when sources of electrical power are located at long distances, so the dosing pump can be placed as closest as possible to the irrigation site by direct connecting to the main irrigation pipe. By using the dosing pump there are avoided fertilizer losses, and the dosing accuracy is high.

The fertigation plant diagram (Figure 1) suggestively presents only a small number of irrigation pipelines with droppers. The real number of pipes used in a grove of fruit trees is much higher.

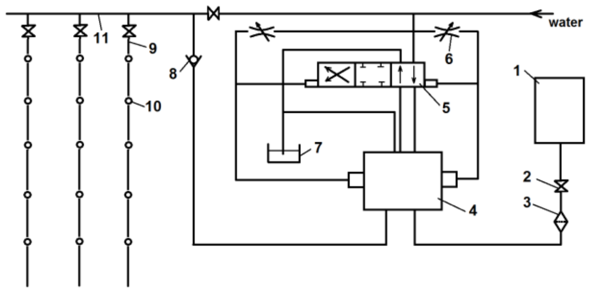

Fig. 1. Diagram of a drip fertigation plant with dropper

1- fertilizer tank; 2- tap valves; 3- filter; 4- fertilizer dosing pump; 5- directional control valve; 6- adjustable throttle; 7- tank; 8- non-return valve; 9- irrigation pipe; 10- dropper; 11- main pipe.

Dimensions of the fertigation plant used in the CFD simulation have been reduced compared to those used during the testing stage in the grove of fruit trees, with no impact on the physical phenomena occurring in irrigation water and fertilizer flow. They are presented in Table 1.

Table 1

Dimensions of the drip fertigation installations with dropper used in the CFD simulation

Dimension	**Unit (**mm)
Diameter of pipelines	28
Diameter of injection pipe for fertilizer particles	12
Diameter of pipe with droppers	16
The inner diameter of dropper	0.8
The length of pipelines	61000
The length of pipe with droppers	20000
The distance between the pipes with droppers	3000
The distance from the injection pipe to the first pipe droppers	600

Geometry of the pipe network and distribution of droppers are presented in Figure 2. The number of simulated fertigation pipes is 20, with 40 droppers on each pipe. The functioning parameters of the fertigation plant have been obtained experimentally, and then used in the CFD simulation process.

The primary fertilizer solution (Magnisal), which is introduced through the non-return valve by the dosing pump, has a concentration of 0.25g/l per an injection pipe diameter of 12mm. Knowing the density of Magnisal fertilizer (800 kg/m^3) there has been calculated the number of particles introduced in the simulation (approx. 4170) to comply with the given concentration. These particles are considered solid and spherical, with a diameter of 100 μm. In the CFD simulation it has been considered as a hypothesis that particles do not chemically interact with water.

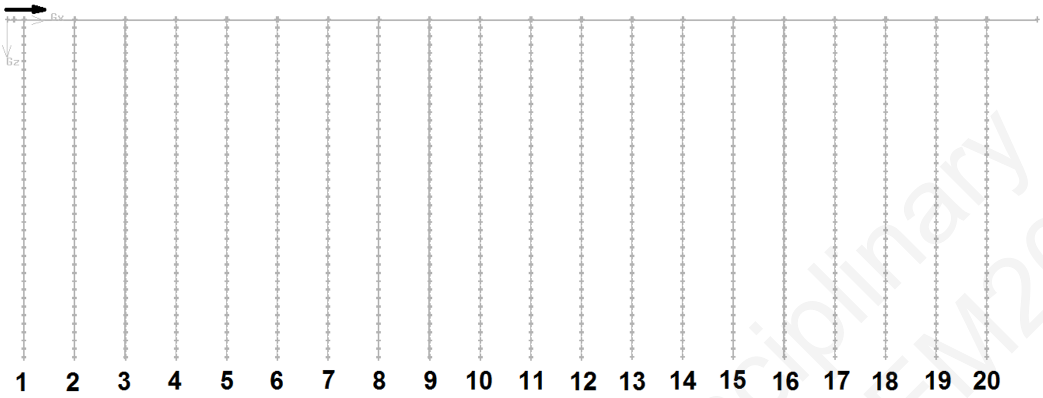

Fig. 2. Geometry of pipe network with fertilization droppers

To increase the accuracy of simulation and prevent the occurrence of the end pipe phenomenon (unsteady velocity due to turbulent flow at pipeline input), the input section has been considered at a distance long enough from the pump so that the input velocity of irrigation water could stay constant over time (u = 0.715 m/s). Particle velocity along the fertilizer injection pipe section has been considered constant (u_p= 0.636 m/s). At the 800 droppers, on the output edge there is imposed free discharge into the atmosphere (outflow), where there is only atmospheric pressure, and overpressure is considered null. Circulation of water and fertilizer through the walls of plant pipes is considered null, too. Water density and viscosity have been considered constant at a given temperature (25˚C), according to the boundary conditions.

Mathematical model necessary for the CFD simulation, specific to the fertigation plant, has at its base flow equations of irrigation water, fertilizer particle trajectory equations, work conditions and restrictions imposed to the process [3]. From the flow conditions, by Reynolds criteria, there has been established a turbulent flow both at the main pipe and at irrigation pipes with droppers. The standard *k-ε* model is the simplest "complete" model of turbulence [4]. This one models the turbulence with two transport equations, which enables independent determination of turbulent velocity and the scale of turbulence length [5]. Values of kinetic turbulence energy *k* and dissipation velocity ε are obtained from the system of transport equations [6]:

$$\rho\frac{Dk}{Dt}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\Pr_k}\right)\frac{\partial k}{\partial x_i}\right]+G_k+G_b-\rho\varepsilon-Y_M \qquad (1)$$

$$\rho\frac{D\varepsilon}{Dt}=\frac{\partial}{\partial x_i}\left[\left(\varpi+\frac{\mu_t}{\Pr_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_i}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}\left(G_k+G_{3\eta}C_b\right)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}; \qquad (2)$$

where: G_k kinetic turbulence energy generation term; G_b floatability term; Y_M compressibility term; Pr_k and Pr_ε Prandtl turbulent numbers for *k*, respectively for *ε*.

The effect of compressibility on turbulence is neglected because fluid velocities are low. The original constants of the *k-ε* model have been determined through tests with water as having the following values: $C_{1\varepsilon}=1.44$; $C_{2\varepsilon}=1.92$; $C_{\mu}=0.09$; $\Pr_k=1.0$; $\Pr_{\varepsilon}=1.3$ [6], [7].

The simulation of particle trajectory as a disperse phase in the irrigation water is made by integrating the balance of forces per a fertilizer particle. Floatability and gravity forces are calculated in a Lagrangian frame of reference [4], and the balance of these forces is described by the equation:

$$\frac{d\overrightarrow{u_p}}{dt}=F_D\left(\vec{u}-\overrightarrow{u_p}\right)+\frac{\vec{g}\left(\rho_p-\rho\right)}{\rho_p}+F_z\,; \tag{3}$$

where $F_D\left(u-u_p\right)$ is the drag force per unit particle mass and

$$F_D=\frac{18\mu}{\rho_p d_p^2 C_c} \tag{4}$$

where ρ density of fluid medium; ρ_p density of solid particles; μ molecular viscosity; d_p particle diameter; C_c Cunningham coefficient is expressed by the Stokes transport law:

$$C_c=1+\frac{2\lambda}{d_p}\left(1.257+0.4e^{-\left(1{,}1^{d_p}/_{2\lambda}\right)}\right); \tag{5}$$

The coupling of disperse phase (fertilizer particles) and continuous phase (water) in the CFD simulation is done through the proposed mathematical model, as long as the continuous phase influences the disperse phase, vice versa not valid. In order to meet this condition there has been solved the flow of continuous phase until there has been obtained stability of the solution, and then there has been solved the discrete phase model [8]. Meshing of the plant was hybrid, developed with Gambit v2.2.3 software, and meshing optimization had as primary goal to avoid any errors in processing stage (Figure 3). For optimization there have been tested 3 different mesh densities with a number of 250,000, 375,000 and respectively 453,000 cells. The mesh with a number of 375,000 cells was optimal for high accuracy simulation and reasonable calculation time.

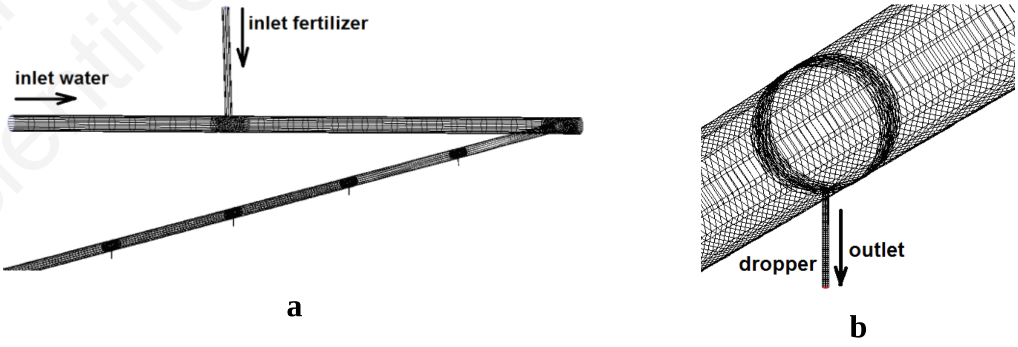

Fig. 3. Hybrid mesh model of the drip fertigation plants with droppers

a. overview b. zoom in- dropper

The simulation software FLUENT creates an algorithm that is based on the two models, to which there have been added a number of additional boundary conditions. Particle trajectory has been developed in several steps for a volume of fluid. Step length factor was initially set to 5 [4], and later for a more precise trajectory it was set to a value of 10.

The convergence criterion used for all variables of solutions has been imposed at the value of 0,001. The CFD simulation has been unsteady, and the number of iterations required for convergence of solutions of the equation system was 2555. Processing of the model under simulation was performed by use of the TYAN workstation (2XCPU-Intel Xeon 3.33 GHz; RAM - 16GB DDR3 2600).

RESULTS AND DISCUSSION

The results are presented as the processing of velocity field, and that of the trajectory of the fertilizer particles in the simulation of fertigation system. The ultimate goal is to present trajectory and dispersion mode of fertilizer particles at the level of 800 droppers, and a tendency to move to their installation. The advantage of a three-dimensional simulation of flow and particle motion is that it provides an overview as close as possible to the real fertigation process in a fruit tree plantation. Additionally, adding a new dimension to the two-dimensional patterns leads to a more complex but more realistic model, given the turbulent flow of the simulation and the opportunity to observe the evolution of particle trajectories. The distribution of the fertilizer particles is carried out uniformly in all of the 20 pipes of the drip fertigation system (Fig. 4).

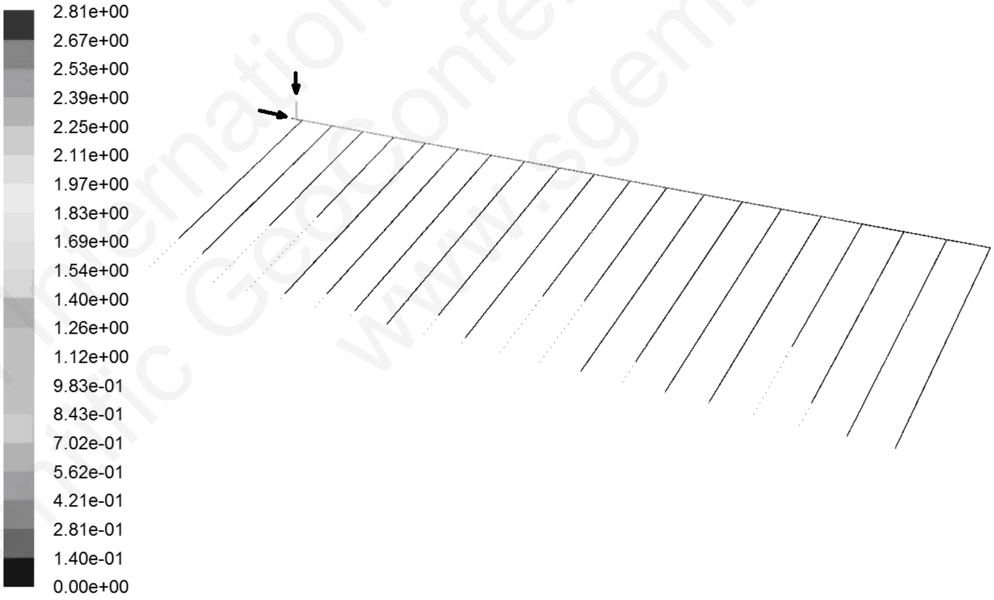

Fig. 4. Distribution of fertilizer particles in the system (color bar - fertilizer particle velocity)

Reducing the linear load and velocity of the final solution and fertilizer particles in the entire system, it appears that at the last and penultimate dropping pipe the particles are distributed fairly evenly over all 40 droppers.

It has been noted that fertilizer particles move too quickly from the first drop entering the installation. Because of this phenomenon, in pipe 1 they reach only till the dropper 33, in pipe 2 only till the dropper 35, in pipes 3 and 4 only till the droppers 25 and 22 respectively, and in pipes 17 and 18 fertilizer reaches only till the droppers 25 and 36 respectively.

The smaller number of dropping fertilizer used for the first 4 pipes is due to the high velocity of the particles in the main pipe to let in a small number of particles in the first half of the installation and a larger number in the last half. The pipes 11 and 12 register a total of only 27 or 25 droppers with fertilizer, but with a more uniform distribution in each dropper. By analyzing the particle distribution of fertilizer in the plant it is observed that only a percentage of 15% of fertigation pipes has fertilized all 40 dropping. The remaining pipes have a lower or higher percentage of the fertilizer dropping. Furthermore fertilizer particle distribution is non-uniform distribution in droppers in the first half compared to the last half of the plant. Knowing the distribution of the fertilizer particle, in all the 800 droppers in the installation there can be carried out a similar analysis of the same type with the fertilizer solution. The fertilizer concentration follows the pattern of particle distribution of fertilizer in the fertigation system.

Since the distribution of fertilizer particles on the first pipe with droppers is uneven as a result of the great length of pipeline (61 m) relative to its diameter (0.028 m) there has been presented velocity field only to the first line with droppers (fig. 5).

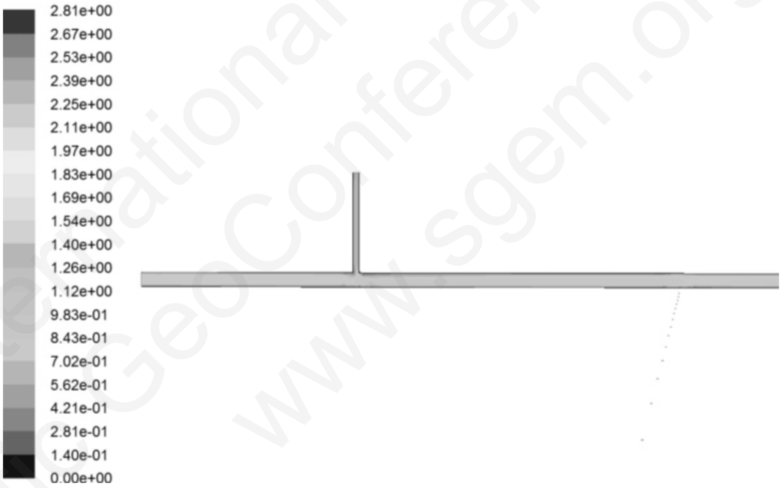

Fig. 5. Velocity field of fertilizers into the main pipe to the first pipe with droppers

The distribution of the velocity field in the median plane of the main pipe to the fertilizer ranges from 0 to 0.72 m/s in the pipe wall to the flow center, and for the vertical pipe of fertilizer input velocity varies from 0 to 0.64 m/s from wall to the flow center.

CONCLUSION

The CFD (Computational Fluid Dynamics) simulation to a drip fertigation plant with droppers used in horticulture has been taken to determine the distribution of fertilizing solution. The diffusion of fertilizers in irrigation water solution is more difficult to track due to very low levels and variation of pressure in the pipeline network. The mathematical model was built based on the assumption that the fertilizer is in the form of solid spherical particles with a diameter of 100 μm which do not chemically interact with water. The concentration and distribution of fertilizer granules and velocity field inside fertigation system is achieved by the CFD simulation, considering turbulent flow with the k-ε model.

The advantage of the three-dimensional simulation of flow and particle motion is that it provides an overview as close as possible to the real fertigation process taking place in a grove of fruit trees. In addition, adding a new dimension to the two-dimensional patterns leads to a more complex but more realistic model, given the turbulent flow of the simulation and the opportunity to observe the evolution of particle trajectories.

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REFERENCES

[1] Kafkafi U., Global Aspects of Fertigation Usage, International Symposium on Fertigation - Optimizing the utilization of water and nutrients, China, 2005, pp 8-23.

[2] Tenu I., Echipamente pentru irigatii, Ed. Tehnică, Stiintifică si Didactică, CERMI, Iasi, 2004, pp. 56-67.

[3] Cârlescu P.M., Modelarea si simularea proceselor fizice industriale, Ed. Performantica, Iasi, 2005, pp. 11-15.

[4] *** Ansys-Fluent, User Guide, USA, 2010.

[5] Patankar S.V., Spalding D.B., A Calculation Procedure for Heat, Mass and Momentum Transfer in Three-Dimensional Parabolic Flows, Int. J. Heat Mass Tran. 14, pp. 1787-1806, 1972.

[6] Vandoormaal J.P., Raithby G.D., Enhancements of the SIMPLE Method for Predicting Incompressible Fluid Flows, Numer. Heat Trans., vol. 7, pp.147-163, 1984.

[7] Launder B. E., Reece G. J., Rodi W., Progress in development of a Reynolds-stress turbulence, J. Fluid Mech., 68, pp. 537-545, 1975.

[8] Kallio GA., Reeks MW., A numerical simulation of particle deposition in turbulent boundary layers, Int. J. Multiphase Flow, 15, pp. 433–446, 1989.