

## CFD MODELING OF THE OPERATING PROCESS FOR SPRAYERS IN VINE PLANTATIONS, WITH RECOVERY OF THE DISPERSED PESTICIDE LIQUID

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**Abstract:** *The operating process of the spraying machines used for pest and disease control in vine plantations is complex and requires studies and research in order to optimize. Inadequate plant protection treatments can lead to high production losses and increased pollution of the environment, and in special of the soil. In order to reduce the amount of pesticide entering the environment studies were carried out on sprayers with recovery of the liquid pesticide which did not remain on the foliage system of the treated plants. An integrated scientific study, based on mathematical modeling and CFD simulation, was performed in order to predict the trajectory of the pesticide droplets dispersed from the nozzles towards the surface of the recovery panel, in various operating parameters. Based on the results of mathematical modeling and CFD simulation of the operating process a laboratory test rig was designed and built in order to perform experimental tests.*

**Keywords:** *nozzle, spraying machine, vine plantation*

### 1. Introduction

The application by dispersing of the pesticide liquid in vine plantation is a complex working process, which involves a continuous equilibrium between maximizing the efficiency of the treatment and minimizing the residuals and environmental pollution as a result of drift and loss of phytosanitary substance.

The working process is affected by different factors, such as dose of liquid pesticide and the dispersed volume [1, 2], distribution of the dispersed liquid [3], the dimensional spectrum of the droplets [4, 5, 6], the volume of air [2, 7, 8], the pattern of distribution and the speed of the airflow, [9, 10, 11, 12], the speed of dispersion of droplets [13, 14], the weather conditions [15], the crop characteristics [16] etc. The large number of adjustments and settings of the spraying machines and environmental parameters involved in vine plantations spraying make the analysis of the workflow as a whole to be difficult, costly and with major implications on the environment.

Therefore, the combine use of integrated mathematical modeling and CFD simulations (Computational Fluid Dynamics) with the experiment is a scientific endeavor, which responds to the new technological requirements.

The number of papers that deal specifically with modeling and CFD simulation is steadily increasing, which leads to a permanent improving the mathematical models by increasing accuracy, while helping to compare different spraying systems and their performance.

This paper presents the mathematical modeling and CFD simulation of the operating of process specific of a sprayer, with the aim to observe the flow of air and the trajectory of droplets from nozzles to the recovery panel. CFD simulation enables the optimization of the settings of the spraying machine in order to obtain uniform dispersions of the liquid pesticide and better recovery rate of the liquid in collecting panel [17].

## 2. Material and research method

### 2.1. The sprayer with recovery pesticide

A pesticide recycling system was designed and built, in order to recover the liquid pesticide which is not retained by the foliar system of the plantation. The equipment was mounted on an universal spraying machine, used for pest and disease control in vine plantations (fig.1). The equipment consists of the folding subframes (1) and the polycarbonate panels (2), provided with the gutters (3) at the lower end. The folding subframes of the panels may be displaced in two positions by the means of the hydraulic cylinder (4): operating position and transport position. The liquid pesticide recovered by panels and which was drained into the gutter is absorbed and transported by pump in the receiver tanks, allowing the measurement of the recycled liquid with the help of two graduated cylinders. Two flowmeters were inserted into the hydraulic circuit in order to measure the liquid flow rate to the nozzles.



**Fig. 1.** Aggregate for pest and disease control with equipment to recover the dispersed liquid pesticide

During the laboratory tests AMT 1.2 full cone spray nozzles manufactured by ALBUZ were used; the operating pressure was set at 0.4, 0.6 and 0.8 MPa. The fan speed was 1400 rev/min, and the recycling panels were positioned at 1900 mm distance from the axis of the machine and at a height of 300 mm above the ground. Air velocity in the discharge area of the equipment was measured (fig.2); the spray angle of the nozzle was also evaluated (fig.3).



**Fig. 2.** Determining the speed of air from behind the fan



**Fig. 3.** Determining the angle of dispersion at the pesticide liquid to the level of nozzle

## 2.2. CFD simulation

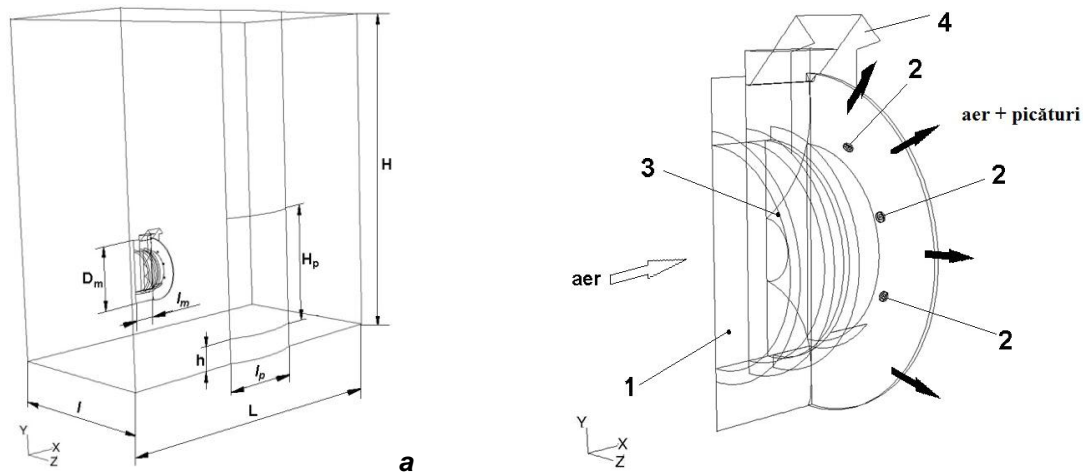
The CFD simulation of the liquid spraying process was performed using TYAN graphical station and the ANSYS-FLUENT software, which uses the most complex mathematical models of fluid flow between programs existing commercial currently.

To exemplify theoretical calculation algorithm of the spraying equipment with recovery of pesticide liquid and simulation the processes of spraying pesticides liquid have been used in the actual values, obtained by measuring the specific parameters of the process, determined in the experimental tests.

Real values, resulted form the experimental tests, were used in order to present the theoretical algorithm used for the simulation of the liquid spraying process the

In order to simulate the air flow process and the droplets trajectory a working domain was defined, which included the geometry of the spraying machine (*fig.4*). The development of the 3D geometry and model discretization are important steps in the simulation process. The geometry must reflect as faithfully as possible the spraying machine model, and the approximations should not affect the air flow and droplets trajectory.

The GAMBIT software allows the simplification of the spraying machine geometry without affecting the simulation results. this solution was chosen in order to reduce the size of the geometric file and the subsequent one, resulted through geometry discretization. Thus the computing time is reduced and less computin resources are needed for the studied assembly. The dimensions of working domanin, for both simulation and experiment, are shown in *Table 1*.

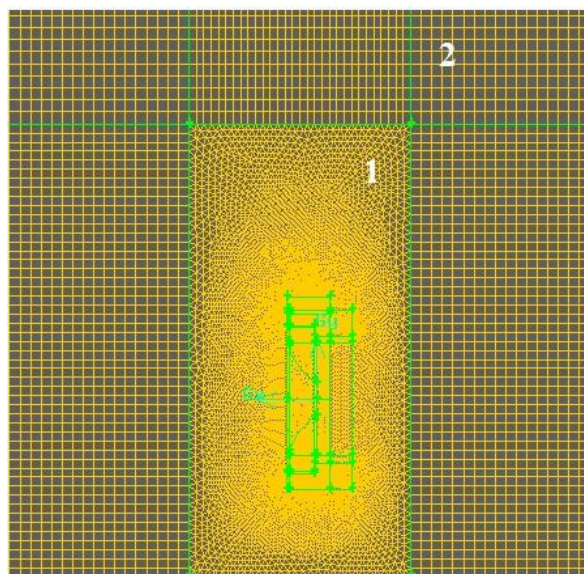


**Fig. 4.** Defining the scope (analysis, stimulation): a - with panel the recovery of pesticide liquid and spraying machine; b - s the geometry of praying machine (enlarged view): 1 - fan; 2 - nozzles; 3 - interior deflector; 4 - external deflector.

**TABLE 1:** The dimensions of working domain used in experiment and simulation

Name of dimension	Symbol	Dimensions (mm)
The distance from the collector panel at the axis of spraying machine	$l$	1900
The length of the working area	$L$	4055
The height of the working area	$H$	4140
The width of the collector panel	$l_p$	1053
The height of the collector panel	$H_p$	1440
The height from soil at the collector panel	$h$	300
The diameter of the spraying machine	$D_m$	846
The width of the spraying machine	$l_m$	310

The finite volume discretization method consists in obtaining a system of algebraic equations, typically linear, which approximate the solution of the differential equations. The unknowns of the system are the values of the desired function, in the nodes of the discretization net, which approximates the simulation domain. Depending on the size of the simulation domain and complexity of the process, to which the uniqueness conditions are added, the number of resulting equations is very large, requiring a powerful computer for system solving. The discretization of domain simulation is hybrid, being carried out in GAMBIT program and consists of two regions, as follows: the region of spraying machine (unstructured discretization) and the region surrounding the spraying machine (structured discretization) (*fig.5*). The sensitivity of discretization was achieved through consecutive tests, by increasing the number of elements in a row from 930.500 up to 3.292.188. For the maximum number of elements there were no more changes in the velocity profile. Thus the meshing errors were eliminated. The quality of the mesh for the entire simulation domain in *fig.5* was 0.78.



**Fig. 5.** The network discretization with two regions: 1 - the region of spraying machine; 2 - the region surrounding of spraying machine.

The speed of entering air ( $u$ ) was obtained through measurements in radial direction, using a hot wire anemometer; the velocity profile was approximated using a polynomial function:

$$u = 3 \cdot 10^{-10} \cdot x^5 - 3 \cdot 10^{-7} \cdot x^4 + 0.0001 \cdot x^3 - 0.0189 \cdot x^2 + 1.0754 \cdot x + 0.0441 \quad (1)$$

The level  $x = 0$  was considered in the inner side of the input surface contour (towards the central axis of the spraying machine).

The physical parameters of air and droplets used for the simulation have were: air viscosity  $\eta = 1.789 \cdot 10^{-5}$  Pa·s, air density  $\rho = 1.225$  kg/m<sup>3</sup>, viscosity of the liquid  $\eta_1 = 0.001003$  Pa·s, liquid pesticide density  $\rho_p = 1080$  kg/m<sup>3</sup> (at 25°C). The flow rate per nozzle of pesticide liquid used for the simulation was 0.025 kg/s.

It was assumed that the droplets of liquid pesticide have the same diameter. According to the ASAE S572.1 standard, the droplets resulting from AMT 1.2 -ALBUZ full-cone nozzle are within class XC (extremely coarse - extremely high), with diameters between 503 and 665  $\mu\text{m}$ . The average diameter of the droplets used in the simulation was 584  $\mu\text{m}$ , and the droplets were considered to be perfect spheres. An important condition introduced into the simulation was the jet angle  $\theta$  at the nozzle exit, with a measured value of 22°. For the AMT 1.2 - ALBUZ nozzles the radius of the nozzle outlet is  $r = 0.6$  mm.

The cartesian system coordinates for the origins of three nozzles are shown in *Table 2*.

**TABLE2:** Coordinates of the origins and the direction of dispersion for the three nozzles

Nozzle *	Coordinates origin nozzle * (m)			Spray direction		
	x	y	z	x	y	z
1	0.060984	0.264285	0.221761	0	0	1
2	0.060984	0.112321	0.326203	0	0	1
3	0.060984	-0.071729	0.337460	0	0	1

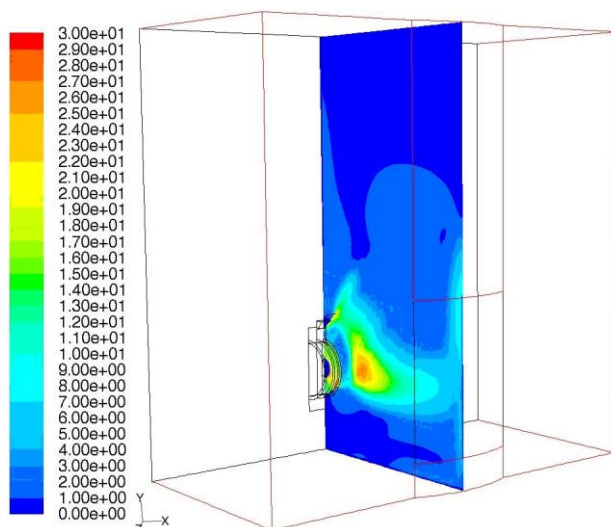
\* The numbering begins with one of the nozzles of the spray top of the machine

In order to achieve the stability of the calculation process the following sub-relaxation factors were used for the air flow: pressure - 0.3; moment - 0.7; density - 1; turbulent kinetic energy - 0.8; turbulent dissipation rate - 0.8; turbulent viscosity - 1.

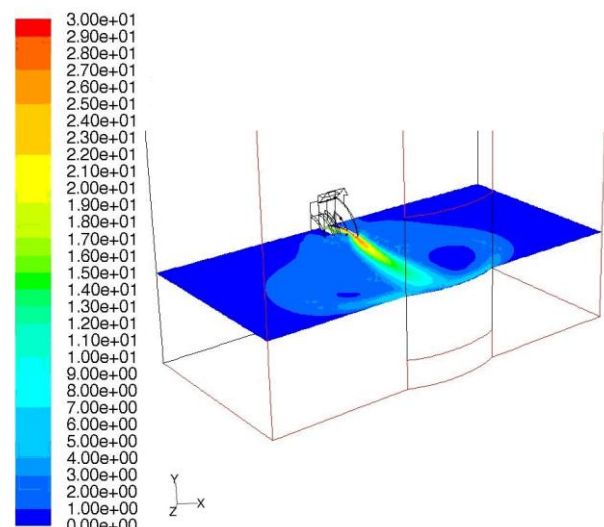
### 3. Results and discussions

The processing results are presented in the simulation domain as velocity fields, flow lines and droplets trajectory, respectively. The final aim was to present the trajectory and droplets dispersion pattern on the collecting panel, and also the displacement tendency on the surface of the panel. The advantage of three-dimensional simulation of airflow and droplets movement is that it provides a realistic view of the real spraying process. The use of the third dimension to the bi-dimensional models, which was made possible due to more performant computers, led to the achievement of a more complex and more realistic model, showing the turbulent flow of the liquid and the evolution of the flow lines paths. In order to obtain a more complete analysis of the flow in the simulated field, several vertical planes were used for displaying the velocities field.

The velocity field presented in fig. 6 shows an increased air circulation at the edge of the panel, on its entire height. In the median vertical plane of the collecting panel, which also includes the spraying nozzles, the velocity field displays a small central core where the velocity reached values up to 30 m/s. This core extends to the center of the panel with average values of air velocity of 5 m/s.



**Fig. 6.** The field of air velocities in the plane YOZ at the middle of the panel manifold,  $u$  (m/s)



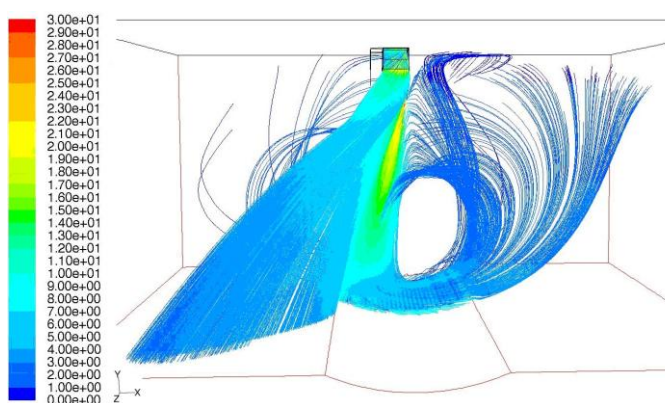
**Fig. 7.** The field of air velocities in the plane XOZ at the middle of the panel manifold,  $u$  (m/s)

The air velocity field in the XOZ plan presents an asymmetry at the exit of the spraying machine. In the nozzle area air speed recorded higher values towards the deflector and decreased from the nozzle to the fan. This explains the slightly tipped out air stream. The average value of the air

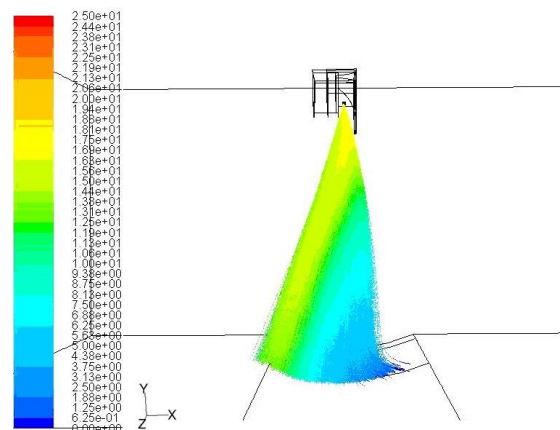
velocity at the outlet of the spraying machine was 20.5 m/s, for a fan impeller speed of 1400 rev/min. The velocity profile has a horseshoe shape in the vicinity of panel, with the stagnation point shifted from the vertical central axis of the panel. This velocity distribution results in a more intense circulation on the left side of the panel (fig. 7).

Turbulence intensity reaches its maximum value in the upper and lower parts of the spraying machine due to the shape of the upper deflector and to the bottom effect in the lower part of the machine. The average velocity in the nozzle area was 20 m/s, gradually decreasing towards the collecting panel. The flow lines begin to “wash” the collecting panel on its diagonal, which represents the locus of the stagnation points. The flow lines density is higher in the upper side of the panel diagonal, thus increasing air circulation. This is also the place where the flow lines are displaced to the right, over the panel; the displacement is enhanced by the upper deflector of the machine which has the same shape as the velocity profile. The formation of a vortex was noted on the concave panel, with a smaller diameter at the upper part of the panel, which increases progressively towards its bottom (fig.8).

The droplets trajectory is affected by the air flow. The CFD simulation was based on the assumption that droplets are carried by the air flow, described by the velocities field and flow lines. The tendency of the flow lines to deviate from the right side of the panel to its left side is also shown in fig. 9, where the liquid jet is observed from above the spraying machine. The average velocity of the droplets was 14 m/s on the right side of the collecting panel and decreased to 3.5 m/s on the left side. The droplets reaching the panel were displaced towards the left side and because of the weight they fall towards the collecting area. This behavior was also seen in the experiments referring to the pesticide recycling rate.



**Fig. 8.** The lines of current flow of the air from the spray machine to the collector panel, a top view of the plane XOZ in the direction  $-OX$ ,  $u$  (m/s)



**Fig. 9.** The trajectory of the droplets and the dispersion of the sprayer to drip collector panel according to the speed  $u_p$  (m/s), plan view XOZ in the direction  $-OY$

#### 4. Conclusions

1. The modeling and CFD simulation of spray process is a useful optimization constructive geometry panel collection and of adjusting operating parameters of spraying.
2. As the CFD simulation, and experimentally it observed that the distribution power lines, or droplets of pesticide, mainly arrive on the collectors.
3. By increasing the speed of air at the level of the bottom nozzle, a cyclone is formed at the bottom of the higher and lower panel to the top panel. Thus, the flow lines tend to wash his diagonal panel.
4. The trajectory of the droplet is influenced by both the air flow and the position of the panel relative to the axis of the spraying machine.

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