U.P.B. Sci. Bull., Series D, Vol. 80, Iss. 1, 2018 ISSN 1454-2358

SPRAYER DEVELOPMENT FOR VINEYARDS

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Our current research aimed at developing a newly-designed sprayer, which can be used for plant protection purposes in vineyards. The primary task was to maintain a high energy efficiency level; hence every sprayer nozzle was assembled with a separate controlled fan- and drive motor unit. The fan design was finished and was checked by flow simulations (ANSYS CFX), too. After a first prototype of the fan was ready, the characteristic curve was measured which was compared to the results of the simulations. If the difference between the results of the measurements and the simulations is below 10%, then we can say that the simulations offer adequate solutions.

Keywords: radial flow fan, simulations, efficiency, plant protection, vineyards, measurement, characteristic curve, sprayer

1. Introduction

Regarding sprayers, the type of the machine and the operation costs are very important aspects. The suppliers' market is almost fully saturated: there are several products to be found from Germany, Italy, Slovenia, the Czech Republic, Denmark, the Netherlands and Poland. Efficiency is the main aim in the development process, therefore the tank is larger and the width of the machine is also wider. The spraying quality depends very much on the nozzles, which should not be neglected. The sprayers were mounted onto a frame, where the distance between each column was 500-1000 mm, and about 3-4 pieces of sprayers were fixed on each column. The sprayers can be controlled separately or in groups.

The research institute in Geisenheim has made a big progress by developing this spraying equipment. The aim was to develop a new fan which has lower energy consumption and lower spray consumption too. At the end of the project, the machine will have to be tested in order to see whether the problems arisen while using former agricultural sprayer can be surmounted using this machine.

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This article is about a special kind of pest control equipment, which is generally used by vineyards. The novelty of this machine is in its unique controllable 6-8 sprayers. In this case every nozzle has its own fan, which produces and maintains the necessary pressure and volume flow of the compressed air. There is a large selection of fans available on the market. The radial type of the fan was chosen here with 50-120 m/s air velocity and 2000-7000 m³/h volume flow of ambient air.

2. Material and method

The first step of the research was to develop a fan with correct fluid parameters. Therefore we made some simulations with different fluid parameters to get the volume and the capacity of the machine. The Computational Fluid Dynamics (CFD) allowed us to develop nearly the best fan. The iterations continued until the target threshold was reached. In this case the best performance was granted by the bended and densely bladed impeller, which made the 1500-2000 m³/h flow capacity possible (Fig. 1.). The fan was fitted in a metal housing.

2.1 Design of the fan

In case of an impeller, forward or backward bended blades generate completely different flows. In addition, the cylinder surface of the blades makes a loss in pressure. This loss can be avoided with a twisted blade design.

However, this solution is hardly ever used because its production is rather complicated. The density of the blades is proportional to the number of blades and it depends on the diameter ratio and on the average angle of elevation of the blades (logarithmic spiral line through the inlet and outlet edges) [Gruber]

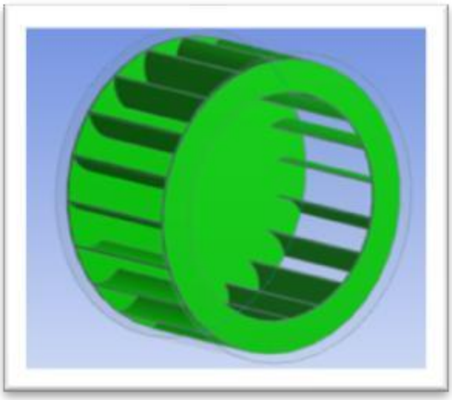


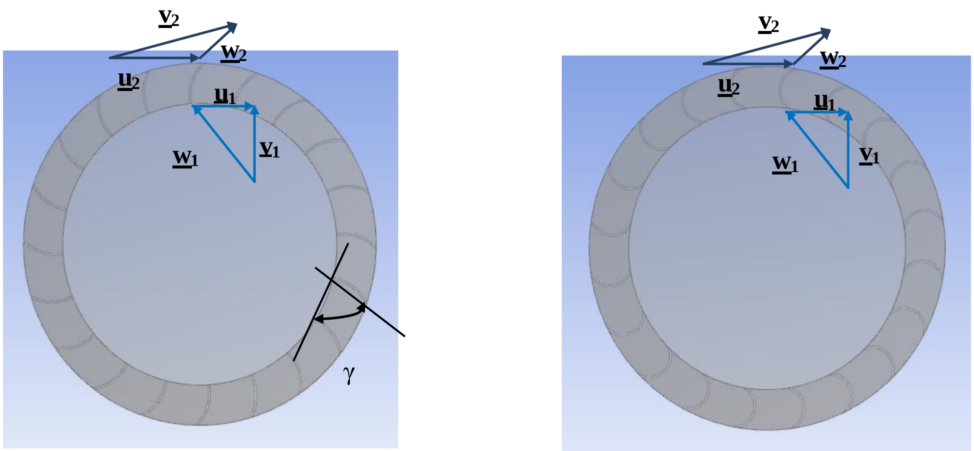
Fig. 1. Impeller geometry

This fan has a simple geometry: the blades are cut from a cylinder and then welded onto the basic plate. The welding has to be of a good quality, because any deformation has to be avoided. We have chosen forward-bending blades for the impeller because this type of fan can create higher volume of airflow with a smaller geometry design.

The rounding off of the incoming geometry and the width of the impeller are examined with the flow and other theoretical methods. One part of the loss stems from the route of the air (the air comes from axial direction and turns into radial direction). The radial gap has many benefits in case of a wide impeller. The air flowing through the gap helps the even distribution of velocity. It reduces the flow separation in the inner side of the frontal side of the impeller.

The parameters of the first plan include perimeter velocity, impeller angle, the degree of inclination of the impeller, the length of the impeller and the number of the impeller. The γ angle can be defined from the velocity triangles. (Fig. 2.)

The transported volume can be concluded from the velocity triangles (perimeter velocity (u), absolute velocity (v), relative velocity (w)) so it has to be drawn on both sides (inlet and outlet). The relative velocity vector is in the tangential direction of the blade. In case of the first blade ((Fig. 2a) collision velocity is created because there is a significant difference between the angle of the tangential direction of the blade's inlet edge and the angle of the relative velocity vector direction. As a result, the inlet loss is considerable as well. Thus the second impeller geometry (Fig. 2b) was more convenient due to the lower collision velocity.



a b

Fig. 2. Velocity triangles

2.2 The optimal planning of an impeller house with computer simulation

It is usually hard to approach to a good solution due to the complicated flow field around the impeller and the variable parameters. That is why computer simulations are used. Three different types of geometry were examined (Fig. 3) during the simulations and both the backflow and the performance were investigated. In the case of the first model, the house of the fan has large outlet perimeter (Model 1), in the case of the second model (Model 2), we examine a geometry resembling a snail shell, while a completely different inlet perimeter with a different curve can be seen.

Model 1. Model 2. Model3.

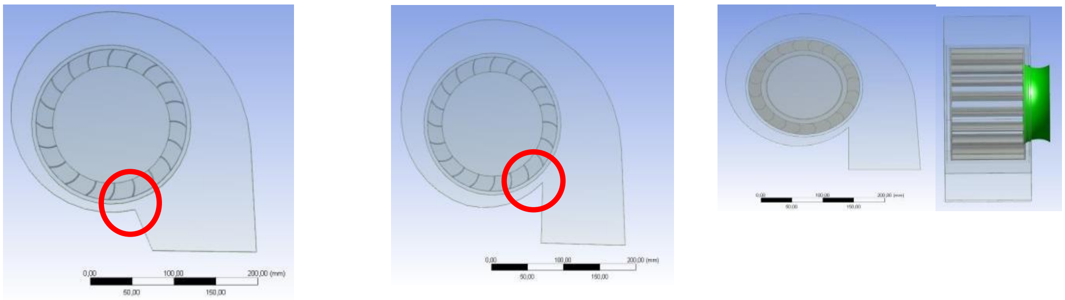


Fig. 3. Examined geometry

The significant pressure generated in the house together with the transformed inlet perimeter create a boundary layer upgrade.

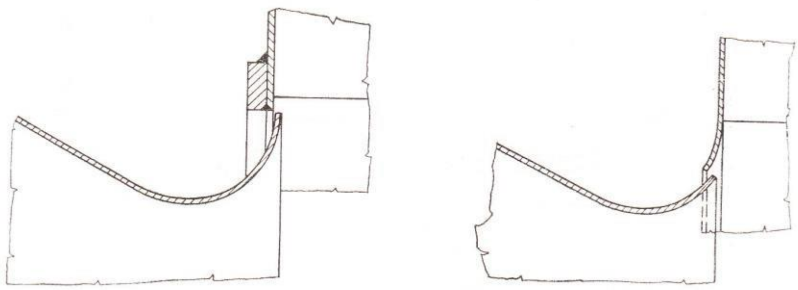


Fig. 4. Types of gaps

As the air enters the house– in an axial direction, it should turn into a radial direction in the inlet perimeter. This normally leads to flow separation in the fan. The volume of this separation can be reduced by installing an inlet cone (see Fig. 4.). Figure 4 shows two types of solution which enable the even division of the velocity field and the reduction of the separation.

2.2.1 Structure of the simulation

When creating the flow area, we prepare a negative, which means that we draw the air flow area. The inlet and outlet surfaces are defined in order to be able to use the model more easily in the future. A boundary layer is defined next to the walls because the flow velocity along the walls is zero due to the wall friction. The boundary layer represents the intermediary between the walls and the fluid flow.

When defining the boundary conditions, the flow features of the inlet and outlet side have to be given. Next the attributes of the fluid and the applied turbulence model need to be given. The impeller is defined as a rotating wall, which rotates with a constant number of revolutions (3500 rot/min). The performance of the engine and its rpm are given but the air capacity can be defined from the simulations.

A turbulence model has to be defined for the calculations. The task of the turbulence models is to suggest a procedure, a formula or even differential equation to calculate the turbulence tension. In addition, it does not require much time on the computer and RAM memory. A turbulence model suitable to calculate all the flow problems the same way has not been created yet. The turbulence model of our choice is the SST (Shear Stress Transport).

3. Results and discussion

The velocity field, the volume of the flow, the moment of the impeller and the performance of the equipment are given by the simulation results. Figure 5 shows the velocity distribution on the surface of the flow field in the case of all three models. In the case of the first model we can see that the top part of the impeller does not work (the dark blue color in the red circle indicates low velocity, 0-2 m/s). This is not the case with the second model where higher velocity can be achieved on average (less extent of the dark blue part). The value of the velocity has been increased by the modified inlet perimeter and the volume has also risen due to the new impeller design in case of the third model. This is shown on Figure 5 with yellow in the case of the third model. The velocity of the inlet volume is 35-45 m/s while it is only 20 m/s in the case of the two other models. The other reason why the volume doubles is due to the design of the inlet perimeter and of the gap between the house and the impeller. This is the result of the simulation in the case of the third model. Later we will validate these results with measurements.

1. Model (2926rot/min) 2. Model (2926rot/min) 3. Model (2926rot/min)

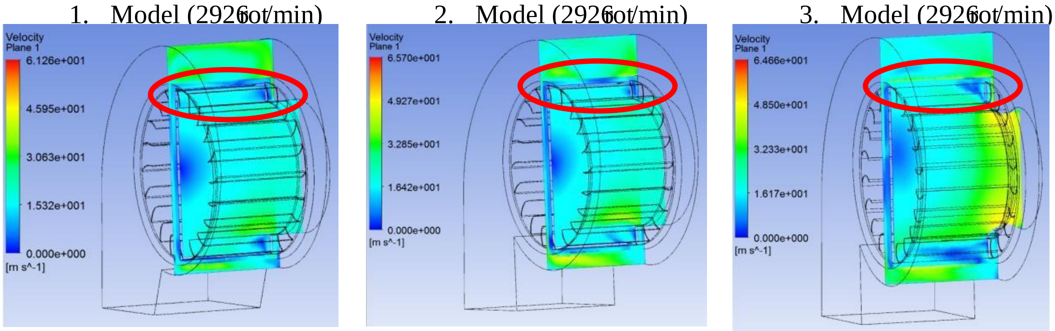


Fig.5. Average velocity distribution

The advantage of having examined three different geometries is to obtain an optimal impeller. In order to change the mass flux exiting the impeller, an adjustable blade is built in the house otherwise the grapes cannot be sprayed properly. Guiding blades, which change the outlet velocity field, are installed in the outlet perimeter. Having manufactured the geometry, we have compared the results of the simulations with the results of the measurements.

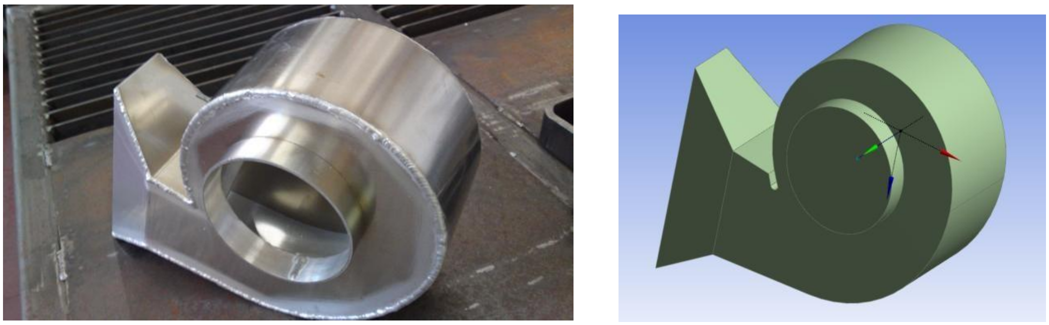


Fig. 6. Geometry of the diffusor unit

As the geometry of the house changed, a separated flow region was created along the walls of the house. As a result the outlet velocity field became uneven. The uneven outlet velocity field can be improved by the guiding blades, which were installed in the outlet perimeter. Several simulations had been carried out by the time the optimal position for the blades was found. The simulations support the concept that the correctly installed guiding blades improve the evenness of the outlet velocity field.

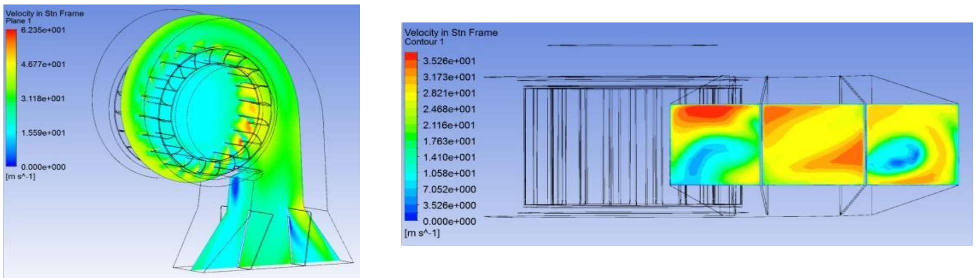
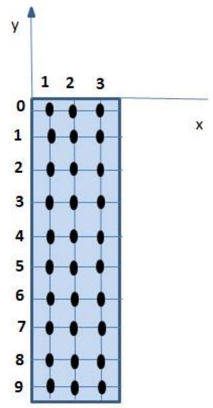


Fig. 7. Velocity field with guiding blades

The results of the simulations and the results of the measurements are compared. Velocity was measured by Prandtl-tube and inclined manometer. Velocity was measured right at the outlet perimeter and at 500 mm from this position. The outlet perimeter was divided into 27 measurement points and velocity was measured at each point three times. Measurements were carried out with and without guiding blades where the rpm reached 2926. Figs. 8-9 show the results of the velocity with and without guiding blades as well as the division of the outlet perimeter. The results of the measured velocity without guiding blades show (Fig. 8) the outlet velocity values differ (the green area represents the low velocity field 10-15 m/s, while the red area indicates the higher velocity field 20-25 m/s). [5]

Measurement points



Velocity (m/s)

0	15.3	12.8	18.4
1	12.5	16.0	19.3
2	15.3	19.5	20.8
3	18.4	19.6	22.0
4	20.9	19.1	17.0
5	21.5	19.6	18.6
6	24.8	20.5	21.4
7	21.5	23.0	22.7
8	20.0	23.2	22.1
9	19.6	16.4	21.1

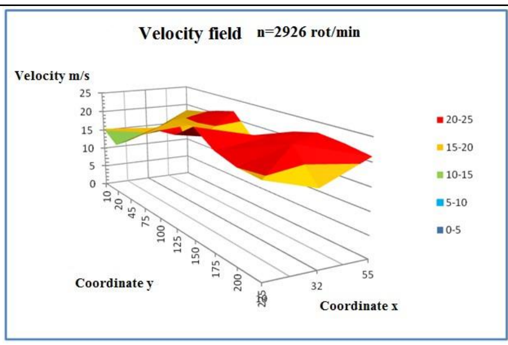
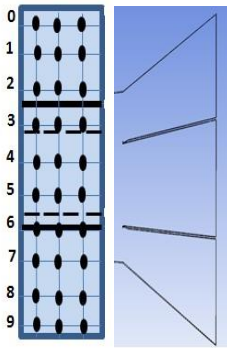


Fig. 8. Results without guiding blades

Velocity (m/s)

Measurement points



0	18.8	16.1	16.1
1	17.7	18.4	20.4
2	24.6	18.9	22.9
3	24.9	22.8	21.0
4	21.0	21.9	22.8
5	24.8	24.2	21.8
6	22.6	23.1	23.5
7	21.9	19.7	22.2
8	18.9	15.7	16.7
9	15.3	16.4	17.7

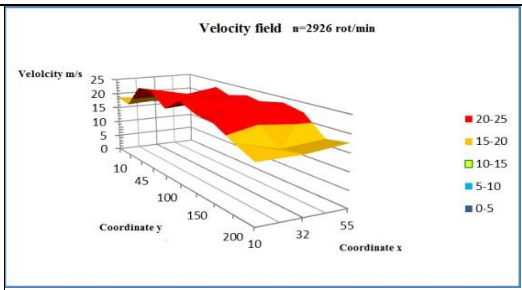


Fig. 9. Results with guiding blades

The outlet perimeter is divided into three parts by the inbuilt guiding blades (see Fig. 9). The velocity field is different in all the three areas. This is calculated in each perimeter:

$$E=(v-v_{average})/v_{average}*100 \qquad (7.1)$$

v – velocity in a measurement point

$v_{average}$ – average velocity at the outlet perimeter

The 0,1,2 line of the measurement points represents the top part of the perimeter, the 3, 4, 5, 6 line represents the middle part of the perimeter and the 7,8,9 line represents the bottom part of the perimeter (see Fig. 9).

Table 1

Rate of unevenness

Area	**0,1,2**	**3,4,5,6**	**7,8,9**
Without guiding blades	-14.2	4.4	8.4
With guiding blades	-5.4	11.9	-10.5

The unevenness calculated by the equation mentioned above can be seen in Table 1 with and without guiding blades. The volume of the unevenness was reduced by 10 percent in the top part of the perimeter when there were not any guiding blades. As a result, the absolute value of the velocity hardly increased, which means about 2 per cent. Fig. 10-11 show the velocity values measured 500 mm away from the outlet perimeter. Fig. 11 shows the variation with guiding blades. In this case, the values of the velocity could not be measured in the part of the perimeter.

Measurement points Velocity (m/s)

1	**3.6**	**5.7**	**5.7**	**5.1**	**0.0**
2	**5.1**	**8.5**	**10.8**	**0.0**	**0.0**
3	**0.0**	**10.5**	**3.6**	**0.0**	**0.0**
4	**0.0**	**7.2**	**6.8**	**5.1**	**0.0**
5	**0.0**	**7.2**	**8.9**	**5.1**	**0.0**
6	**0.0**	**5.7**	**11.4**	**5.7**	**0.0**
7	**0.0**	**0.0**	**9.9**	**10.8**	**5.7**
8	**0.0**	**0.0**	**9.9**	**12.3**	**9.2**
9	**0.0**	**0.0**	**9.6**	**12.3**	**8.5**
10	**0.0**	**0.0**	**7.2**	**10.8**	**9.6**
11	**3,.6**	**9.9**	**7.2**	**8.1**	**4.4**
12	**0.0**	**0.0**	**8.1**	**0.0**	**0.0**

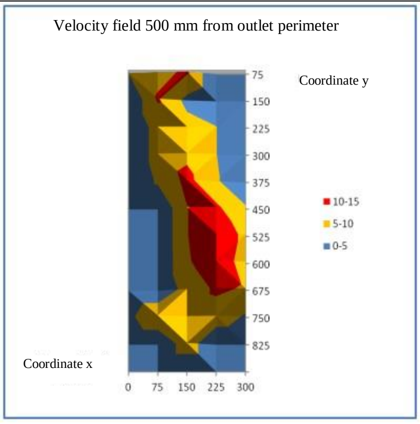
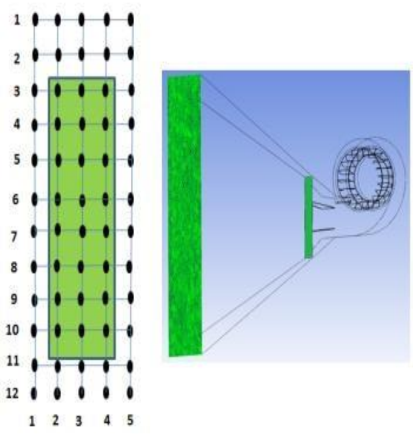


Fig. 10. Measurement points 500 mm from outlet perimeter with guiding blades

Measurement points Velocity (m/s)



1	**0.0**	**7.2**	**11.4**	**9.9**	**0.0**
2	**0.0**	**8.1**	**10.8**	**9.2**	**0.0**
3	**0.0**	**11.4**	**7.2**	**8.5**	**0.0**
4	**0.0**	**4.4**	**9.2**	**7.2**	**0.0**
5	**0.0**	**0.0**	**11.7**	**8.5**	**0.0**
6	**0.0**	**0.0**	**12.5**	**14.7**	**0.0**
7	**0.0**	**0.0**	**8.5**	**13.5**	**0.0**
8	**0.0**	**7.2**	**9.6**	**10.2**	**0.0**
9	**0.0**	**4.4**	**9.2**	**10.5**	**0.0**
10	**0.0**	**0.0**	**8.9**	**9.2**	**0.0**
11	**0.0**	**0.0**	**0.0**	**4.4**	**0.0**
12	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

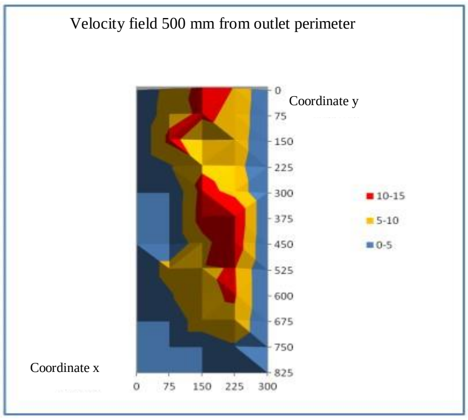


Fig. 11. Measurement points 500 mm from outlet perimeter with guiding blades

The volume and the features of the flow rate can be improved with a funnel placed on the inlet perimeter. As a result, we can achieve better flow around the impeller and the flow rate can increase besides a constant rpm (see Table 2 and simulation pictures).

Table 2

The volume of the flow rate

	With funnel		**Without funnel**	
	With guiding blades	Without guiding blades	With guiding blades	Without guiding blades
Flow rate (m^3/s)	0.3807	0.3864	0.3425	0.2952

Further measurements are planned in the future. The flow field and the flow performance will be first measured by measurement equipment consisting of a measurement frame, a control system and an ultrasound sensor. The frame of the measurement equipment is an aluminum structure which is light and simple. The horizontal rail of the frame stands for the x axis on which the values are measured over a length of 80 cm. During the measurements, the direction and the volume of the air flow are also measured over a certain height 40 cm in front of and behind the impeller. The first measurement point in vertical direction is 50 cm from the ground and further measurement points can be found up to the height of 215 cm (see Fig. 11).

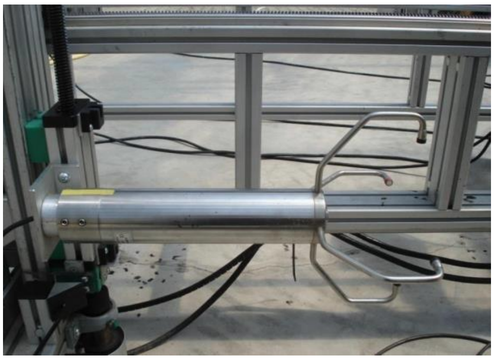



Fig. 12. Transducer "Ultrasonic Anemometer 2D", fans placed one below the other with a 30° axial position

4. Conclusions

The aim of this project was the design and construction of an energy efficient, individually controllable sprayer for plant protection in vineyards. Therefore, in terms of velocity and volume, the requirements of the 6-8 single fans were determined. A virtual model of the fan was designed based on these and flow simulations were performed. After the optimization, a prototype showing the performance on the test bench was designed and manufactured.

The geometry of the designed impeller satisfied the expected physical parameters but the geometry of the outlet perimeter needed to be modified because the flow field was not even. The blades arranged one below the other need to fill a continuous surface otherwise grapes cannot be sprayed evenly. To overcome this problem, a confused was installed at the end of the housing geometry, which changed the outlet velocity field.

After designing the impeller, simulations were carried out followed by the manufacturing of all the geometry. The results of the simulations and the results of the measurements were compared and in order to reduce the volume of the separated flow region, guiding blades were built in. These guiding blades help to reduce the unevenness of the velocity. In order to obtain the best results, the guiding blades were adjusted in several ways and the velocity field was examined in each case.

In the future our aims are the following:

- to improve the efficiency of the impeller by doing more researches with different inlet cone designs,
- to achieve more even velocity by modifying the outlet perimeter geometry,
- to install the already manufactured impellers on the sprayer machine and to carry out more measurements with it,

- to test the spatial velocity field in case of three fans placed one below the other.

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