DEVELOPING A SYSTEM TO CONTROL THE AIR FLOW OF A PNEUMATIC SPRAYER

DESENVOLVIMENTO DE UM SISTEMA PARA O CONTROLE DA VAZÃO DE AR DE UM PULVERIZADOR PNEUMÁTICO

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ABSTRACT: Air flow is of great importance in pneumatic sprayers as it is related to droplets sprayed size. Currently, there is a deficiency in regulating air flow in these sprayers. This work aimed to develop a system to control air flow of a pneumatic sprayer (Berthoud), and evaluate, in relation to air flow, power demanded by PTO and technical parameters of spraying (VMD, coefficient of homogeneity, percent coverage and droplets density), related to air flow. The diaphragm valve was projected using the software CAD, which was later made in galvanized steel and fixed to the fan air inlet. Air flow and power demanded on PTO was evaluated in eight diaphragm aperture positions (100, 90, 80, 70, 60, 50, 40 and 30%), and also using water sensitive papers, parameters of spraying were evaluated through a range of 30 meters in five diaphragm apertures (100, 90, 80, 70 and 60%). At the end it was found that between aperture of 100 and 70%, the closing of diaphragm caused a decrease of 4.56% in air flow. From aperture of 60%, reduction of air flow was more evident, resulting in reductions in air flow of 14.08, 24.00, 35.37 and 47.09% for opening levels 60, 50 , 40 and 30% of diaphragm, respectively. The power demand decreased linearly as diaphragm was closed. The system proved to be efficient to control spraying parameters with reduction of air flow, it has also increased droplet size (VMD), therefore resulted in reducing droplets density. Coverage percentage was influenced only by distance, reducing it as distance from the spray nozzle increased. The coefficient of homogeneity decreased as increased air flow and distanced from the spray nozzle.

KEYWORDS: Pesticides application technology. Spectrum droplets. Diaphragm.

INTRODUCTION

Pesticide application technology is a multidisciplinary field in agriculture as it is related to the control of insects, mites, weeds and pathogenic agents, which considers aspects of biology, chemistry, engineering, ecology, sociology and economics (FERREIRA, 2006).

In most cases a great importance is attributed to pesticide used and little attention is given to the technology of application. However, besides knowing the product to be applied, it is also necessary to know the proper way of application, to ensure that this product reaches the target efficiently, minimizing losses (CUNHA et al., 2005).

In a spraying, sprayer regulation for water volume, droplets spectrum and population are main factors to define pesticide application quality. Chances of hitting target when working with droplets of small diameter is larger, however, according to Cunha et al. (2004) droplets below 100 µm are very subject to drift and those droplets very large (over 600 µm) are subject to runoff. Oliveira et al. (2007) reported that droplets diameter determines the percentage of coverage and also provides potential risk of drift, penetration in plant canopy, evaporation losses, and therefore percentage of total volume applied which remains on the target.

In field conditions the main meteorological factors affecting pesticides applications are temperature, relative moisture and the wind. The two first ones have a marked effect on evaporation and volatilization of droplets sprayed, while wind speed and direction affect drifting (VILLALBA and HETZ, 2010).

Ruedel (2002) reports that wind over 2.78 m s^{-1} affects spraying quality due to excessive lateral movement of droplets, which can promote their off-target.

In works conducted by Yu et al. (2009) it was found that, by reducing relative moisture from 90% to 30%, time for evaporating a droplet of 343 µm reduced from 115 to 52 seconds. But for relative moisture of 60% time for evaporation increased from 40 to 453 seconds with the increase of droplets diameter from 246 to 886 µm.

Working with the herbicides application in wheat crops, Suguisawa et al. (2007) found that effectiveness of herbicides is influenced by

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temperature and relative moisture which affect absorption and translocation of these compounds into the plant.

Although these factors are known, it has been frequently necessary to spray under critical conditions, and several technologies have emerged in order to minimize those factors. In a hydraulic spraying, for example, just changing the spray nozzle allows the grower to apply under unfavorable conditions, considering relative moisture and temperature.

When working with pneumatic system, in which droplet fragmentation occurs due to shearing of a liquid flow caused by air flow at high speed, adjusting the equipment is difficult, because, according to Di Prinzio et al. (2010), in a pneumatic spraying to vary droplets diameter it is through modification of ratio between liquid and air flows.

Mewes et al. (2011), in order to alter fan air flow, changed rotation speed of PTO, however reported that performing this procedure might involve a significant increase in power required by the sprayer, which may raise maintenance cost, reduce tractor autonomy and increase cost of production. These same authors say that if it is necessary to change air flow of the fan, it should be looked for other alternatives instead of adding rotation speed of PTO.

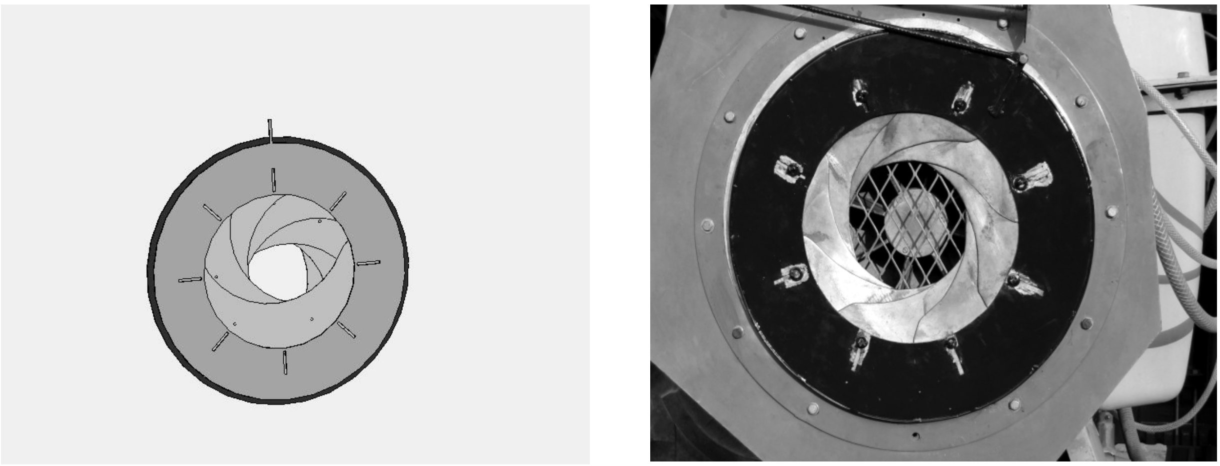
Therefore this work aimed to develop a system to control air flow of a pneumatic sprayer, and evaluate its influence on spraying technical parameters.

MATERIAL AND METHODS

The experiment was conducted at the Laboratory of Agricultural Pesticides Application (LADA) at Department of Agricultural Engineering, Federal University of Viçosa, Viçosa - Minas Gerais.

For the experiment it was used a pneumatic sprayer Berthoud brand, model AF 427, equipped with straight blade radial fan. The sprayer was coupled to a John Deere tractor, model 5705, and 62.5 kW engine rated power.

The diaphragm was designed using the software Computer Aided Design (CAD). This diaphragm was built using galvanized steel plates and fixed to the fan air inlet (Figure 1).



(A) (B)

Figure 1. Drawing (A) and diaphragm setting (B)

Diaphragm was designed in order to open and close in such a way to alter fan air flow. After building and setting the diaphragm, air flows at opening levels of 100, 90, 80, 70, 60, 50, 40 and 30% were determined, they corresponded to openings of 0.27, 0.243, 0.216, 0.189, 0.162, 0.137, 0.108 and 0.081 m, respectively.

To determine air flow supplied by this fan, it was used the American method established by Air Moving and Conditions Association (AMCA). By this method, a wind tunnel was built, equipped with air flow homogenizer tube and a cone valve at the outlet of flow rate regulator duct (Figure 2).

For determining air flow, the sprayer was coupled to a tractor operated with a rotation speed of 2100 rpm on tachometer, producing 56.55 rad s^{-1} (540 rpm) on Power Take-off (PTO) which corresponded to an average rotation speed of 408.42 rad s^{-1} (3900 rpm) on the fan shaft. To check the rotation speed of the PTO shaft it was used a tachometer of model TDR-100. Temperature and relative moisture were obtained using a psychrometer.

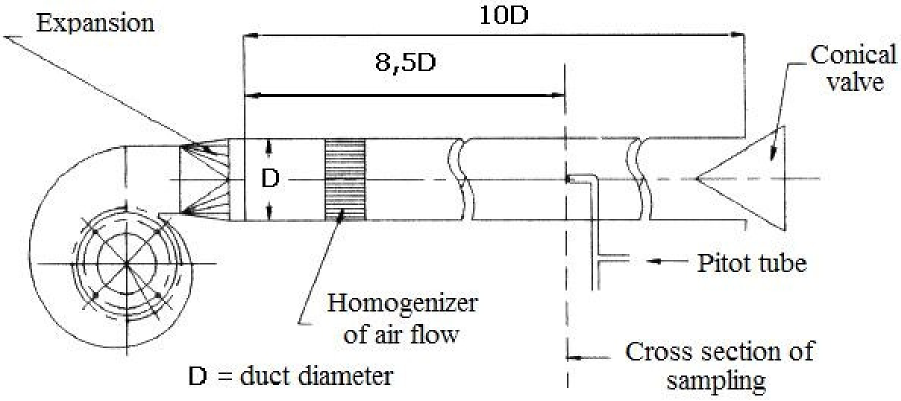


Figure 2. Schematic system of the wind tunnel for tests of centrifugal fans (MESQUITA et al., 1985).

There were four replications to verify air flow in each opening level. From values of flow obtained and static pressure it was possible to determine the fan characteristic curve.

Besides testing the fan as to air flow, PTO power required to drive the fan at eight diaphragm opening levels, was also evaluated. Readings were taken with sprayer in a static situation, without driving centrifugal pump.

Determination of PTO power was performed with aid of an Omega electronic torque wrench, model TQ501-10K with torque of 1130 mN and rotation speed of 600 rpm. Torque wrench was connected to data acquisition system HBM Spider 8, for signal conditioning, and this one to a laptop for storing data. System operated at frequency of 1200 Hz, providing 6000 data of torque every 30 seconds. For greater precision, two thousand lowest data and two thousand highest data were discarded. Control of channel and data initial treatment done by data acquisition system was performed by software CATMAN. Through torque values obtained, it was calculated power required to drive up the fan for each opening level.

Experimental design was set on entirely randomized design, eight diaphragm openings with four replications, totalizing thirty-two experimental units. Variable power demand to drive the fan met demands of normality of errors and homogeneity of variance tests by Lilliefors and Cochran respectively, continuing hence analysis regression variance.

Latter the assessments of spraying technical parameters of were carried out in different diaphragm opening levels and at different distances from spray cannon. For this assessment, under laboratory conditions, water sensitive papers were placed at 1.5 m from sprayer cannon and every 1.5 m it was placed other one, within a of 30 meters stripe, with the total of 20 water sensitive papers per replication. Experimental design was made in entirely randomized design, where first factor evaluated, air flow, was composed of six opening levels equivalent to those from 100 to 50% and second factor, distance from sprayer, consisting of 20 levels (1.5, 3.0, 4.5, ..., 30.0 m) and for each treatment three replications were performed. These opening levels of the diaphragm were used because in preliminary tests from the opening of 50% liquid atomizations in droplets were committed. All spraying were performed at temperatures below 30°C and relative moisture above 70%.

After determining tractor speed 2.6 km h^{-1}, sprayer was positioned at a distance of 1.5 m from the row of water sensitive papers. Before starting all applications wind speed was monitored and spraying were carried out when wind speed was below 5 km h^{-1}. Twenty seconds were spent to stabilize liquid flow rate, after this time application was performed.

Applications were made with two nozzles of four holes 2.5 mm, using pastilles 20 and 30 in primary cannon and a nozzle with four holes of 1.5 mm with pastille 12 in secondary cannon, which provided an average liquid flow rate of 4 L min^{-1}.

After application, water sensitive papers were collected and taken to laboratory aiming to determine parameters of volume median diameter, droplets density, coverage percentage and coefficient of homogeneity. Water sensitive papers were photographed and analyzed using software "Image Tool version 3.0". There was a correction of droplets diameter according to spreading coefficient indicated for water sensitive papers proposed by Chaim et al. (1999).

Prior to proceeding analysis of variance, basic presuppositions of homogeneity of variance by Cochran test and normality of errors by Lilliefors test were checked. Data were subjected to analysis of variance to establish regression models for variables studied. Criteria adopted for choosing models were: significant regression (F test), *Stepwise* criterion to eliminate insignificant coefficients (t test) and coefficient of determination (R^2). Results were analyzed by response of surface using MINITAB ® Release 14 demo version.

RESULTS AND DISCUSSION

During air flow test, temperature varied between 21 and 29ºC and relative moisture above 50%.

Reduction of air flow by closing diaphragm was verified. Closing diaphragm from 100 to 70% promoted a reduction in air flow at 2.34 m^3 min^{-1} which corresponded to a decrease of 4.56%. This happens because the system tries to recover the original air flow. Restriction of fan air inlet area promotes an increase in air speed at air inlet leading to slight reduction in air flow.

Diaphragm opening corresponding to 60% resulted in greater reductions of air flow, obtaining for values of 60, 50, 40 and 30% diaphragm opening, reductions of 14.08; 24.00; 35.37 and 47.09% respectively. Following this reasoning, from opening of 60% due to greater restriction of air inlet area, the system cannot recover the air flow as efficiently.

Reduction of air flow in sprayer nozzle promoted by restraining air inlet with diaphragm, is a consequence of reducing speed of air leaving the system. These results were also obtained by Doruchowski et al. (2009) positioning a diaphragm on the air inlet of a radial fan air blast sprayer to reduce speed of air. These authors observed that closing diaphragm and consequent restriction of fan air inlet, air speed progressively reduced in the sprayer nozzle, which culminated with the purpose of reducing air flow to control drift.

Each diaphragm position determined air speed and flow and later with static pressure data and air flow, it was possible to determine the characteristic curve for sprayer fan.

Each diaphragm opening allowed the fan to operate under specific conditions. In this way it was determined its characteristic curve in function of diaphragm operating conditions (Figure 3).

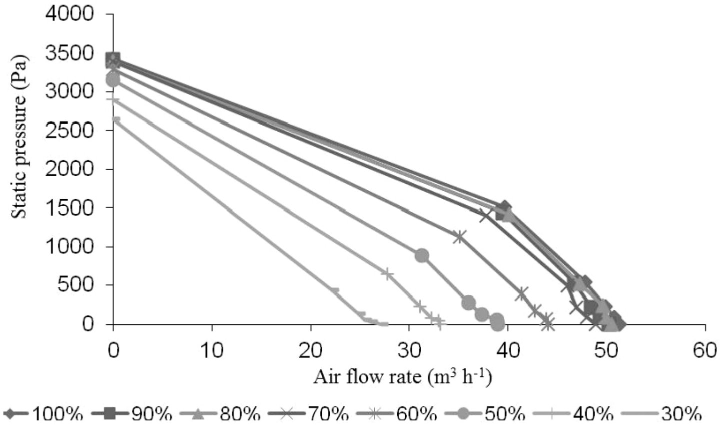
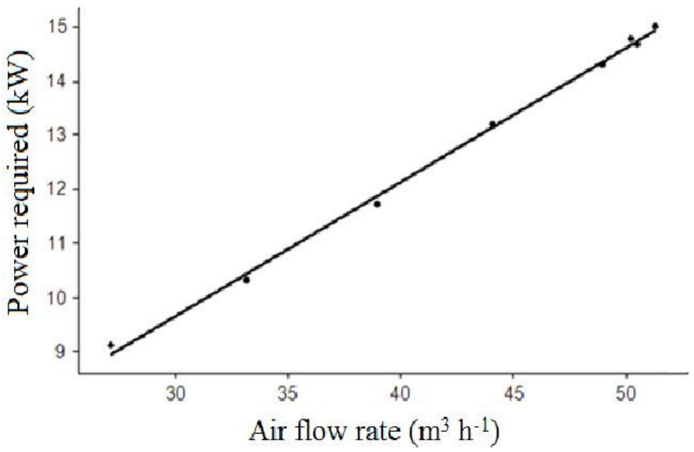


Figure 3. Characteristic curve of radial fan used in sprayer with different diaphragm openings.

Results confirm what was mentioned by Mesquita et al. (1985). As there is a gradual diaphragm closing, lower is the mass of air entering in the system and therefore less kinetic pressure is acquired by the air, justifying reduction in air speed and flow with gradual diaphragm closing.

Figure 4 shows power behavior required by the fan when air flow is changed closing the diaphragm. It was found that reducing the air flow causes reduction of power required by fan. Highest power demand, 14.98 kW, occurred when sprayer produced maximum air flow, 51.28 m^3 min^{-1}. Fan required a power of 8.96 kW when sprayer generated the lowest air flow, 27.13 m^3 min^{-1}.

A lower volume of air suctioned causes the fan a lower resistance to centrifuge it, thus requiring less PTO power, which reduces values of power required.

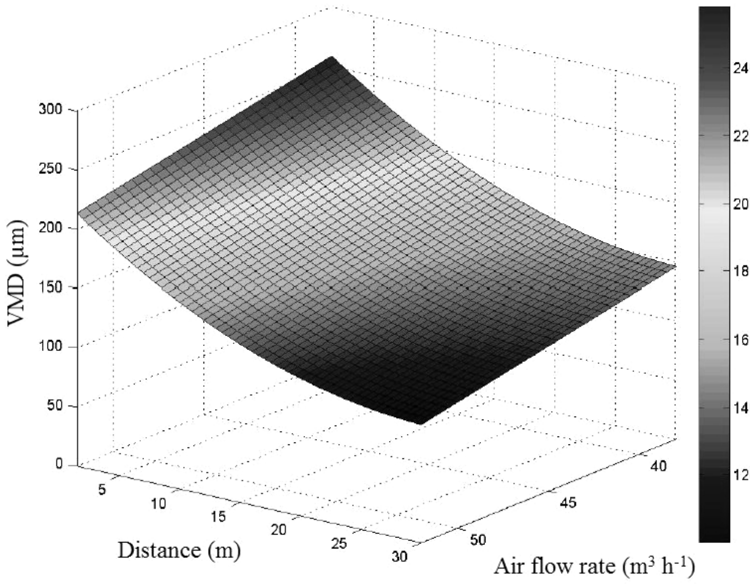


Power required (kW) = 2.21 + 0.249**Air flow (m3 h-1); R2 = 0.997;** Significant at 1% probability by t test

Figure 4. Power demand in PTO according to sprayer fan air flow.

Magdalena (2004) who studied the power demanded to drive up a fan of axial flow and radial flow in static situation, has found values of power demands of 6.73 and 6.78 kW, respectively. Mewes (2009) evaluated the power demanded by a centrifugal fan in a pneumatic sprayer for use in eucalyptus and obtained as result 18.5 kW of power required by the fan.

For evaluating spraying parameters, environmental conditions remained with temperature below 30°C and relative moisture above 65%. It was observed that maximum VMD of 254.86 µm, in a location closer to sprayer, was obtained with 37.98 m3 min-1 flow. As fan was moved away there was a decrease of VMD, obtaining a distance of 30 m, corresponding to 102.4 µm, with the air flow of 51.28 m3 min-1 (Figure 5).



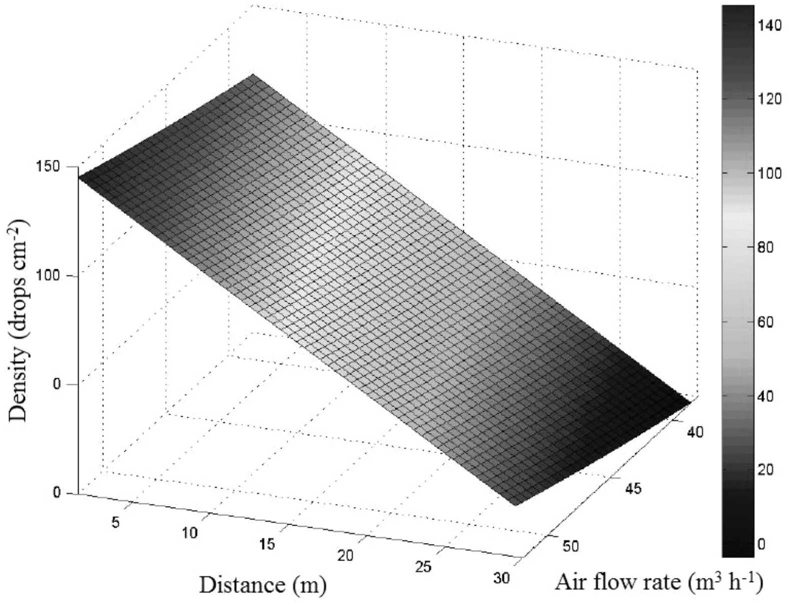
VMD (µm) = 392 - 3.22**Air flow (m^3 h^{-1}) - 7.96**Distance (m) + 0.127**Distance² (m); R^2 = 0.83;
** Significant at 1% probability by t test

Figure 5. Volume median diameter in function of sprayer air flow and spray swath.

Highest values of VMD at distances closer to sprayer were due to the position of secondary nozzle, making a swath overlapped with primary nozzle. It was observed that, when it was used lower air flows, greater VMD was found at the same distance, this is due to the smaller cracking of droplets by air. This result confirms what was mentioned by Di Prinzio et al. (2010). VMD values obtained are in agreement with those described by Minguela and Cunha (2010).

Droplets formed by a pneumatic sprayer are deposited through sedimentation effect and follow a ballistic motion in which droplets of larger diameter, with greater mass and inertia do not follow the air flow over long distances, therefore placing on closer targets. Smaller droplets, on the other hand, with smaller mass and inertia, will keep moving through air flow until their mass and speed are greater than the aerodynamic drag, placing on distant targets. This explains the lower VMD values found over long distances. These results agree with what was observed by Zhu et al. (2007) in which the peak of air speed tends to decline according to the distance, which reduces the air flow drag.

Evaluating droplets density, it was observed that greater densities are in shorter distances from the sprayer and under greater air flow studied, 51.28 m³ min^{-1}. As distance from the sprayer increased, there was a reduction in droplets population (Figure 6).



Density (droplets cm^{-2}) = 94.6 - 4.35**Distance (m) + 0.0213**Air flow² (m^3 h^{-1}); R^2 = 0.65; ** Significant at 1% probability by t test

Figure 6. Droplets density according to sprayer air flow and spray swath.

Droplets density was also lower as the diaphragm was closed, reducing air inlet. Due to the lower intensity of spray solution fractioning by the gradual closing of diaphragm, there happened formation of droplets with larger diameters but smaller amount, which represented on water sensitive papers a decline of population density.

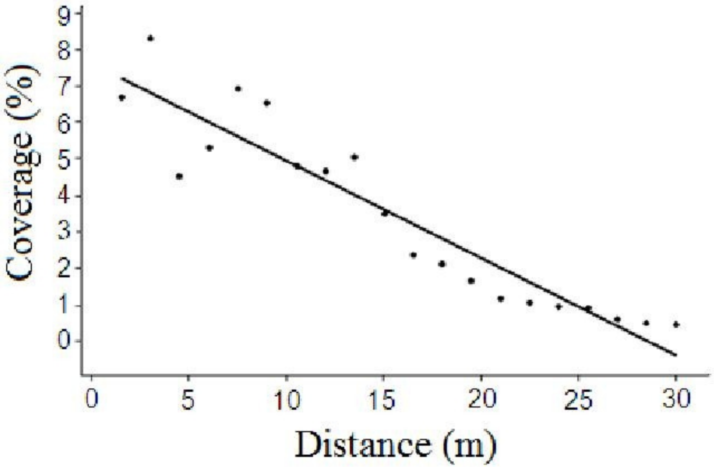
A reduction of useful spray swath according to sprayer air flow reduced, was also verified. This decline caused air flow produced was not able to carry the droplets over long distances in sufficient numbers for a phytosanitary treatment due to the decrease of air speed coming out from the nozzle.

In relation to coverage, it was found that the independently variable air flow did not get a statistical significance on regression model, therefore only distance influenced the coverage obtained (Figure 7).

This result may be explained by compensation of droples formation between air flow under this pressure deficit, i.e. in higher air flows, by the principle of liquid fractionation, there happens smaller diameter droplets formation, but in a larger amount. However in the lower air flow, there also happens formation of larger diameters droplets, but in smaller amount, causing an approximate equality between coverages generated by different air flows, and it might be attributed to the fact of variable does not have significant on regression model established for explaning the coverage parameter.

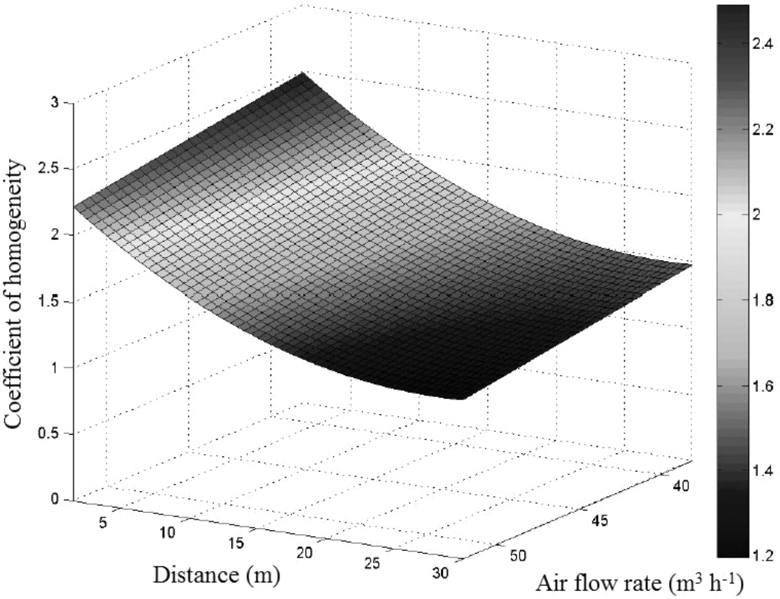
Coefficient of homogeneity is a parameter which examines the relation between values of volume median diameter (VMD) and number median diameter (NMD) of a droplets population, being possible to obtain the amplitude of difference between diameter of these droplets.

In this study, homogeneity coefficient showed decreasing values with increasing distance from water sensitive papers to sprayer. This is explained by reduction of VMD along the spray swath, which causes the droplets placed on collector target do not show great differences among their diameters, reducing the coefficient of homogeneity (Figure 8)



Coverage (%) = 7.58 - 0.267**Distance (m); $R^2 = 0.72$; ** Significant at 1% probability by t test

Figure 7. Percentage spray coverage in function of spray swath.



Coefficient of homogeneity = 3.35 - 0.0195**Air flow (m^3 h^{-1}) - 0.0816**Distance (m) + 0.00146**Distance² (m); $R^2 = 0.72$; ** Significant at 1% probability by t test

Figure 8. Coefficient of homogeneity according to sprayer air flow and spray swath.

In spraying the coefficient of homogeneity, when analyzed together with other parameters of spraying helps the grower to regulate his sprayer in order to carry out a treatment with maximum efficiency and minimum losses for the environment.

CONCLUSIONS

System proved effective in controlling air flow.

As diaphragm closed there was a reduction of air flow.

PTO power demand decreased linearly with decrease of air flow.

With reduction of air flow, droplets diameter increased and therefore reduced droplets density.

RESUMO: Nos pulverizadores pneumáticos, a vazão de ar é de grande importância uma vez que está relacionado ao tamanho das gotas pulverizadas. Atualmente, verifica-se que existe a deficiência na regulagem da vazão de ar, nestes equipamentos. Sendo assim objetivou-se com este trabalho desenvolver um sistema de controle de vazão de ar em um pulverizador pneumático (Berthoud) e avaliar quanto à vazão de ar, potência exigida na TDP, e os parâmetros técnicos da pulverização (DMV, coeficiente de homogeneidade, porcentagem de cobertura e densidade de gotas). Projetou-se o diafragma com o auxilio do programa computacional CAD e que posteriormente foi confeccionado em aço galvanizado e fixado na entrada de ar do ventilador. Avaliaram-se as vazões de ar e a potência exigida pela TDP em oito posições de abertura do diafragma (100; 90; 80; 70; 60; 50; 40 e 30%), e também, com o auxílio de etiquetas hidrosenssíveis, avaliou os parâmetros da pulverização, ao longo de uma faixa de 30 metros em cinco aberturas do diafragma (100; 90; 80; 70 e 60%). Ao final verificou-se que entre as aberturas de 100 e 70%, o fechamento do diafragma promoveu um decréscimo de 4,56% na vazão de ar. A partir da abertura de 60%, a redução da vazão de ar foi mais evidente, obtendo-se reduções na vazão de ar de 14,08; 24,00; 35,37 e 47,09% para as aberturas de 60, 50, 40 e 30% do diafragma, respectivamente. Quanto à exigência de potência, este reduziu linearmente à medida que se fechou o diafragma. O sistema demonstrou ser eficiente no controle dos parâmetros da pulverização, com a redução da vazão de ar, aumentou o tamanho das gotas pulverizadas (DMV), consequentemente acarretou na redução da densidade de gotas. A porcentagem de cobertura foi influenciada somente pela distância, reduzindo-o conforme se distanciou do bocal do pulverizador. O coeficiente de homogeneidade reduziu à medida que aumentou a vazão de ar e se distanciou do bocal do pulverizador.

PALAVRAS-CHAVE: Tecnologia de aplicação e agrotóxicos. Espectro de gotas. Diafragma.

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