Using the Measurement-Based Approach to Emulate the Behavior of a Sensor for Internal Hydraulic Pressure Drop Measurements of Sprayers in the Agricultural Industry

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***Abstract*—Related to the quality of the agricultural spraying processes, the variable hydraulic pressure plays an important role. All spray nozzles when operating are subjected to the hydraulic pressure along the boom. Furthermore, in real sprayers systems the losses in the hydraulic pressure which occur along the boom, where one may find the placed nozzles, are in general verified with the use of pressure sensors in each nozzle. However, such arrangement has high costs for the agricultural producers and involves a larger complexity in the electronics for signal processing, monitoring and control. The hydraulic system of agricultural sprayers has a direct analog in electric circuits, and thus, it is possible to be represented as an equivalent circuit formed by a voltage source and a resistance which characterizes the internal loss of the system. This paper, presents a method that makes possible the evaluation of the hydraulic pressure drop in bars of sprayer systems considering the fluid hydraulic resistance as a part of a sensor element, associated with a point-wise Thévenin's equivalent measurement method. This makes feasible such evaluations with lower cost and greater accuracy, as well as the control of the pressure drop. Thus, taking into account a metering-based approach it was possible to obtain a parametrized relationship among operating conditions and fluid resistances. Therefore, it was possible to obtain the hydraulic equivalent of a sprayer system with direct injection based only on the hydraulic flow and pressure measurements. The results have shown that is possible to get the hydraulic equivalent resistance with a relative error equal to 2.1529%.**

Keywords*–*Metering; Measurement theory; Parametrized model; Pointwise Thévenin's equivalent; Electrical-hydraulic analogy; Agricultural quality sensor.

I. INTRODUCTION

Today, hydraulic systems can be found in a wide variety of applications, also in agriculture. For such systems it is important the determination of the internal losses occurring not only for the establishment of valves' upstream and downstream pressure but also to calculate the flow rates through piping systems. Additionally, such information can help in the establishment of the flow rate range, associated with the design and size of the pumps, compressors, turbines and the relief headers to ensure that back pressure on the relief devices not preventing them from functioning properly [1].

The fluid hydraulic resistance is a function of the flow regime, therefore being dependent of the Reynolds number and the relative pipe. The Reynolds number for pipes, in turn, is a function of the velocity (m/s), density (kg/m^3), and viscosity ($Pa{\cdot}s$) of the fluid, as well as of their internal diameters. Since the temperature also affects the Reynolds number, it becomes important to take that into account when one is working with sprayers systems [2], [3]. Besides, the fluid hydraulic resistance is subject to temporal variations, and requires considerable effort for its determination. In this scenario a sensor that can measure the internal losses of the hydraulic boom pressure in sprayers is very much required.

Pesticide application is a vital component for food security, whose production is directly connected to pest control. Sprayer is the machine used to apply liquid chemicals on plants to control pest and diseases. In addition, it can be used to apply herbicides to control weeds and to spray micro nutrients to enhance plants growth. There are many types of sprayer's commercially available for producers and they are designed for its own particular duties and use. Regarding to such matter one may find backpack sprayers, hand compression sprayers, self-propelled sprayers and pull-behind sprayers, among others.

The manual application method was the first to be used in agriculture, but they have the disadvantage to present a higher risk to the human resources. On the other hand, turning off sprayers when there is no target, or adjusting application rates based on canopy size and density became to be essential for production with sustainability, i.e., in such matter the automated sprayers play an important role. Close to the 90 decade, manufacturers introduced precision spraying technology in boom sprayers [4]. Despite being still an open field for research and innovation, in this direction the variable rate methods, using the Global Position System (GPS) and the Geographic

Information System (GIS) technologies were integrated into boom sprayers and became already commercially available.

The GPS and GIS have been popularized and the combination of these two technologies allowed the diffusion of Precision Agriculture (PA) in the entire world. The PA brings together the use of technologies for the management of soil, inputs and crops, in a manner appropriate to the spatial and temporal variations in factors, which affect their productivity, in order to increase efficiency.

The adoption of PA for localized application of agrochemicals can reduce pesticide wastage and environmental aggression, providing a more efficient production of large-scale food and increasing agricultural productivity. With localized application of agrochemicals, herbicide savings is in the order of 30 to 80% compared to the uniform application in the total area. Automatic sprayers designed and developed for localized application are currently available, allowing the use of large volume of syrup, covering large agricultural areas [5]–[8].

In this field of knowledge, there are the use of conventional and direct injection sprayers system. The first type of direct injection system was developed between the 70's and 80's decades. However in that time such a system presented high cost, complexity of operation and low performance. According to Baio and Antuniassi [7], the main characteristic of direct injection systems is related to the storage of the diluent (water) and the pesticide in separate containers.

The mixing is carried out only at the time of application, by injection of the pesticide into the piping, which carries the syrup to the nozzles of the sprayer. The amount of injected pesticide can be accomplished, among other ways, by controlling the rotation of the piston or peristaltic injection pumps. The main advantages of the injection system are the reduction of risks involved during the application process [9].

Other aspects one should be taken into account, in relation to this matter, is the benefit/cost rate is terms of the use of energy in the agricultural machinery. The success of agriculture, manufacturing, transportation, military systems and construction machinery owes much to the efficient use of fluid energy. Most fluid energy systems are configured with a positive flow displacement pump that is large enough to meet the flow requirements of many circuits. Different work functions require a variety of flow and pressure values to provide the desired operation. Branches of the system therefore must include specific flow and pressure regulating valves.

In the process of agricultural spraying, it is of great importance to know the value of the fluid resistance of the spray boom since, variations in this resistance can affect the quality of the application, i.e., size and volume of drops, distribution of drops on the crop and the drift of the drops produced by the wind [10]. Droplet size and distribution are critical factors in such processes because can be affected the penetration, coverage and drift of the application on the crop [11].

The design of a hydraulic system can be improved with the use of mathematical simulation. Numerous approaches to energy systems modeling fluids and components, can be found in the literature. Analysis of a fluid feed system can cover the flow distribution, the functioning of components, or a combination of both. Most of the useful equations for fluid analysis are derived from the law of conservation of energy, the principle of continuity, and Newton's second law [12].

Equations used to calculate flow in circuits involve the use of empirical expressions or laboratory-derived flow coefficients. Therefore, when two or more circuits are used simultaneously, the principle of continuity may not be obeyed exactly, because of the use of such empirical coefficients. To model a flow regulating valve, a good medium must also be used to define how the flow divides in the active circuit branches.

Usually, this is done by writing a set of equations to determine the desired pressure and flow values, which can be solved via an iterative method. Iterative methods work well for steady state flow conditions, however, they are difficult to apply to non-steady state operations. In relation to such subject Akers and collaborators have shown a method based on electrical-hydraulic analogy was proposed [2]. In this method, fluid pressure, flow, and flow resistance are analogous to voltage, current, and electrical resistance, respectively. The method uses the basic principle of the Ohm's law, also referred to as the hydraulic Ohm.

On the other hand, a fluid moves inside a pipe occurs a fluid friction with the inner walls of this pipe and a turbulence of the fluid with itself. This phenomenon causes the pressure inside the pipe to gradually decrease as the fluid moves and the pressure decrease is known as the pressure drop. In this way, the load loss would be related to a resistance to the passage of the flow of the fluid inside the pipe, this resistance is known as fluid resistance and affects directly the monomeric height of a pump denoted H and its volumetric flow denoted Q. The pressure (p) can be related to the volumetric flow rate by:

$$p = f_a \frac{L\rho}{2DA^2} Q^2 \tag{1}$$

for a rough pipe with turbulent flow or:

$$p = \frac{8\pi L\mu}{A^2} Q^2 \tag{2}$$

for a flat tube with laminar flow, where f_a is the coefficient of friction [dimensionless], ρ is the specific mass of the fluid [kg/m^3], L is the equivalent pipe length [m], D is the internal diameter of the pipe [m], A is the inner area of the straight section of the pipe [m^2] and μ is the absolute viscosity of the fluid [$P_a \cdot s$].

The coefficient of friction f_a, sometimes known as a Moody friction factor or also as a distributed load loss coefficient determined by mathematical equations, is a function of the Reynolds number (Re) and relative roughness. Experimental identification of f_a is more common due to the non linear characteristics involved. For pipes that undergo changes in pipe diameters, in general, flow type or over-curves, fluid resistance may be related to the remainder of the fluid system by:

$$\sqrt{\Delta P} = RQ \tag{3}$$

where ΔP is the pressure drop across the hydraulic element and R is the fluid resistance. For a tube, the fluid resistance is given by:

$$R = \sqrt{f_a \frac{L\rho}{2DA^2}}. \tag{4}$$

For a hole, the fluid resistance is given by:

$$R = \sqrt{\frac{\rho}{2}} \frac{1}{C_d A} \tag{5}$$

where C_d is the discharge coefficient [unit-less].

The next sections of the paper are organized as follows. In Section II, the methodology used to obtain the function relating the hole diameter with the flow in a nozzle is given. In Section III, an experimental validation of the pointwise Thévenin's equivalent and the nozzle flow using a laboratory sprayer setup is performed. Finally, some concluding remarks are presented in Section IV.

II. METHODOLOGY

The well known Thévenin's equivalent circuit of a linear circuit is composed of an equivalent impedance and voltage, which for some cases are organized just with a resistor and a source of continuous voltage. This equivalent circuit is obtained through Thévenin's Theorem:

Theorem 1 (Thévenin's Theorem):

$$\begin{aligned} V_{th} &= V_{oc} \qquad (6)\\ R_{th} &= \frac{V_{oc}}{I_{sc}} \qquad (7) \end{aligned}$$

where I_{sc} is the short-circuit current and V_{oc} the open circuit voltage [13]–[16].

The Thévenin's equivalent circuit can be represented by Fig 1. In Fig. 1, the voltage and current are described by:

$$\begin{aligned} I &= \frac{V_{th}}{R_{th} + R} \qquad (8)\\ V &= RI = -R_{th} I + V_{th}. \qquad (9) \end{aligned}$$

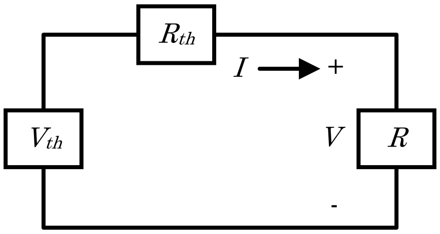

Figure 1. Thévenin's equivalent circuit.

Let $y(1)$ and $y(2)$ denote current measurements taken with values of load R in Fig. 1 for $R(1)$ and $R(2)$, respectively. According to Bhattacharyya and collaborators [17] and Mohsenizadeh and collaborators [18], the Thévenin's equivalent can also be obtained by solving the linear equation system, in terms of α_0 and β_0:

$$\begin{pmatrix} y(1) & -1 \\ y(2) & -1 \end{pmatrix} \begin{pmatrix} \alpha_0 \\ \beta_0 \end{pmatrix} = \begin{pmatrix} -y(1)R(1) \\ -y(2)R(2) \end{pmatrix} \tag{10}$$

where α_0 and β_0 are given by:

$$\begin{aligned} \alpha_0 &= R_{th} \qquad (11)\\ \beta_0 &= V_{th}. \qquad (12) \end{aligned}$$

if one is considering a linear characteristic then is possible to write:

$$\begin{aligned} V_{oc} &= V_{th} \qquad (13)\\ I_{sc} &= \frac{V_{th}}{R_{th}}. \qquad (14) \end{aligned}$$

Otherwise, one can consider, as a further step, the electric analog already described in Section I, then $V = \sqrt{\Delta p}$ e $V_{th} = \sqrt{\Delta p_{th}}$. Now, let $y(1)$ e $y(2)$ be a measure of flow in the boom with the nozzles of interest, where $R(1)$ and $R(2)$ correspond to the equivalent fluid resistance of the nozzles of the boom of interest, thus:

$$\begin{pmatrix} Q(1) & -1 \\ Q(2) & -1 \end{pmatrix} \begin{pmatrix} \alpha_0 \\ \beta_0 \end{pmatrix} = \begin{pmatrix} -\sqrt{\Delta p}(1) \\ -\sqrt{\Delta p}(2) \end{pmatrix} \tag{15}$$

where α_0 e β_0 are given by:

$$\begin{aligned} \alpha_0 &= R_{th} \qquad (16)\\ \beta_0 &= \Delta p_{th}. \qquad (17) \end{aligned}$$

where R_{th} and Δp_{th} are the internal loss equivalent and the internal pressure equivalent, respectively. As the behavior of pressure and flow is non-linear, then there will be more than one possible representation of the Thévenin's equivalent. If the measurements are taken as close as possible to each other, it is then said that a pointwise Thévenin's equivalent is obtained.

It is known that the flow in a nozzle is a function of the hole diameter denoted d, pressure and other hydraulic parameters, which may change with different types of nozzle. Then, it is possible to find a function which relates the hole diameter with the flow in a nozzle. If consider the rank in relation to parameter d and pressure p of the matrices appearing in the description of the flow Q as one, again according with Bhattacharyya and collaborators [17] it is possible to find:

$$Q = \frac{\beta_0 + \beta_1 d + \beta_2 p + \beta_3 dp}{\alpha_0 + \alpha_1 d + \alpha_2 p + dp} \tag{18}$$

where $\beta_0, \beta_1, \beta_2, \beta_3, \alpha_0, \alpha_1$ and α_2 are constants and $(\alpha_0 + \alpha_1 d + \alpha_2 p + dp) \neq 0$. To find these constants, one should take just 7 measurements with different values of d and p and solve the following linear system:

$$\begin{bmatrix} 1 & d(1) & p(1) & d(1)p(1) & -Q(1) & -Q(1)d(1) & -Q(1)p(1) \\ 1 & d(2) & p(2) & d(2)p(2) & -Q(2) & -Q(2)d(2) & -Q(2)p(2) \\ 1 & d(3) & p(3) & d(3)p(3) & -Q(3) & -Q(3)d(3) & -Q(3)p(3) \\ 1 & d(4) & p(4) & d(4)p(4) & -Q(4) & -Q(4)d(4) & -Q(4)p(4) \\ 1 & d(5) & p(5) & d(5)p(5) & -Q(5) & -Q(5)d(5) & -Q(5)p(5) \\ 1 & d(6) & p(6) & d(6)p(6) & -Q(6) & -Q(6)d(6) & -Q(6)p(6) \\ 1 & d(7) & p(7) & d(7)p(7) & -Q(7) & -Q(7)d(7) & -Q(7)p(7) \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \\ \alpha_0 \\ \alpha_1 \\ \alpha_2 \end{bmatrix} = \begin{bmatrix} Q(1)d(1)p(1) \\ Q(2)d(2)p(2) \\ Q(3)d(3)p(3) \\ Q(4)d(4)p(4) \\ Q(5)d(5)p(5) \\ Q(6)d(6)p(6) \\ Q(7)d(7)p(7) \end{bmatrix}. \tag{19}$$

III. EXPERIMENTAL VALIDATION

The Agricultural Sprayer Development System (SDPA) used is located at the Laboratory of Agricultural Precision Spraying of the Embrapa Instrumentation (Fig. 2) in São Carlos, SP, Brazil [9], [19], [20]. The goal is to obtain linear pressure and fluid resistance equivalent by selecting a boom with nozzles of interest using regular measurements. This is possible by solving (10).

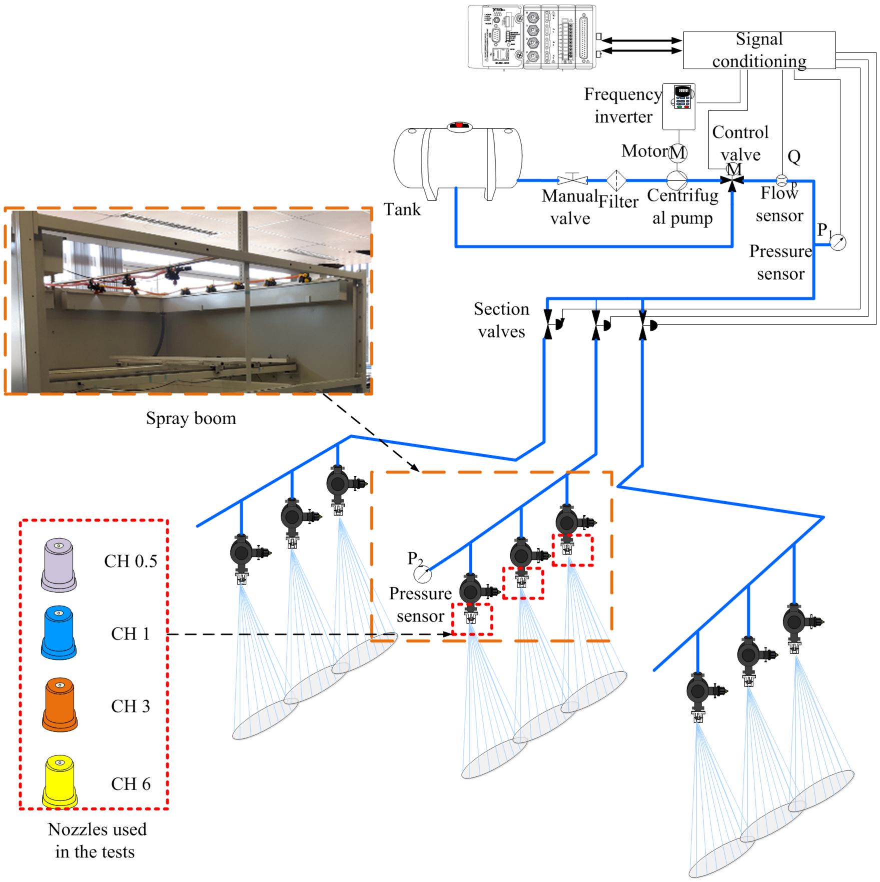

Figure 2. Hydraulic and electrical configuration of the SDPA for testing and validation.

A. Thévenin's Equivalent Validation

To obtain the hydraulic Thevenin equivalent, according to the proposed methodology, only two different fluid resistances are required. However, it is necessary that when the fluid resistance changes, a significant variation of pressure and flow occurs at the point of interest. Otherwise, if any of these measures are kept constant, the equivalent will have the trivial solution.

As the pressure is regulated in the system, a pressure variation of approximately 0.1 bar was considered significant because of the inherent noise of the spray sensors. The objective is to extract the Thévenin's equivalent of the central sprayer boom which is also shown in Fig. 2. All nozzles of the central spray boom are of type CH05.

1) Measurements set up: Each sprayer boom has 3 spray nozzles. First, the pump pressure was set at 3.5 bar and the pressure at the center boom spray nozzles was found to be about 3.48 bar. After this verification, just one nozzle was changed to type CH3. The pressure in the spray nozzles rose to 3.47 bar and was therefore considered as noise. Another attempt was made on in the same nozzle that was replaced by a nozzle type CH6 (which allows the greatest possible flow between the nozzles of this line). The pressure in the nozzles rose to 3.46 and was again considered as noise. Two nozzle were then replaced by CH3 type nozzles and the pressure in the spray nozzles was found to be 3.44 bar, also considered to be noise. In this way, all the nozzles of the central bar were changed to type CH3 and the pressure in that time was equal to 3.39 bar. This pressure drop was then considered as significant and thus concluding that for the system to stop regulating the pressure in the bar it became necessary to change all the nozzles of the bar.

To extract the Thévenin's equivalent, only two different nozzles are required. However, to validate the obtained equivalent, three nozzles were used, where the third nozzle has an intermediate fluid resistance between the other two nozzles used for extraction of the equivalent. Then, the nozzles of the central boom were changed in the row of full cone nozzles and the pressure and flow measurements taken. The data are shown in Table I.

2) Results: Using (15), the following equivalent was obtained:

$$\Delta P_{th} = 3.4394 \ [bar]$$
$$R_{th} = 0.0649 \ [bar \cdot min \cdot L^{-1}].$$

TABLE I. DATA OBTAINED FOR DIFFERENT FULL CONE NOZZLES

Nozzles	Pressure [bar]	Flow [L/min]
CH05	3.4046	0.535
CH3	3.3491	1.420
CH6	3.2946	2.230

Thus, this equivalent was used to estimate the flow of arbitrary pressure values. The result is shown in Fig. 3. The error of estimated flow is 2.1529%.

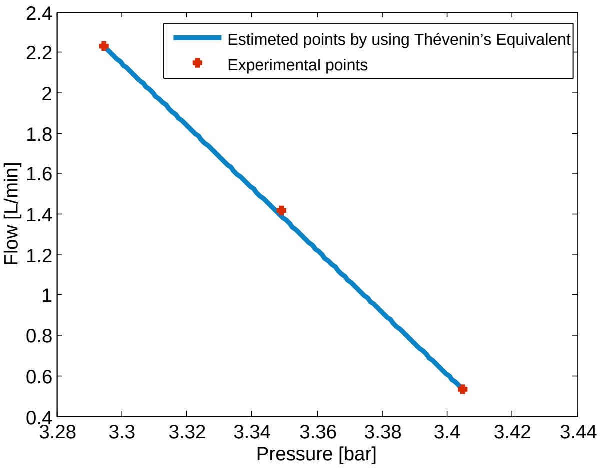

Figure 3. Thevenin equivalent for full cone nozzles.

B. Nozzle Flow Validation

To validate (18) which relates the flow to the hole diameter, a single nozzle was used. The datasheet of a nozzle MAG CH, produced by MAGNOJET®, was used. There it is possible find the values of pressure and flow for each nozzle. The hole diameter was measured using a pachymeter. The 7 points shown in Table II were selected, which cover all the producer table, and were used to solve the linear system (19). With the solution of (19), it was possible to generate the surface shown in Fig. 4.

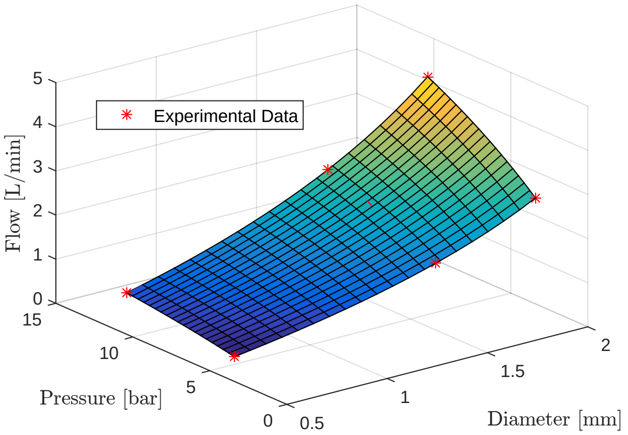

Figure 4. Surface relating the hole diameter d and the pressure with the output flow for the full cone nozzle.

TABLE II. SELECTED MEASUREMENTS FROM THE MAGNOJET PRODUCER DATASHEET.

Nozzle	Pressure [bar]	Q [L/min]	d [mm]
CH05	3.4	0.56	0.5
CH3	3.4	1.5	1.5
CH6	3.4	2.4	2
CH05	10.4	0.94	0.5
CH3	10.4	2.55	1.5
CH6	10.4	4.08	2
CH3	7.6	2.2	1.5

Now, it is possible to predict the flow of the nozzle given the diameter of the hole and the pressure in the nozzle. In Table III, there are shown the results of a prediction using the nozzle CH1.

TABLE III. PREDICTED FLOW AND THE CATALOG FLOW TO CH1 NOZZLE USING THE SURFACE

Pressure [bar]	d [mm]	Predicted flow [L/min]	Catalog Flow [L/min]	Relative error [%]
3.4	1	0.94	1	5.90
4.8	1	1.10	1.2	8.00
6.2	1	1.25	1.33	6.17
7.6	1	1.38	1.47	6.39
9	1	1.49	1.63	8.54
10.4	1	1.60	1.74	8.39

By comparing the prediction given by (18) to the flow provided in the manufacturer's catalog, an average relative error around 7% can be found, which is an acceptable error considering all the involved parameters.

IV. CONCLUSION

In this paper, the measurement-based approach was used to emulate the behavior of a sensor to allow the quality analyses of direct injection sprayers. With few measurements, the fluid resistance equivalent of a piping system was obtained. In addiction, a flow function of a full cone nozzle relating the nozzle internal diameter and pressure were estimated. The results obtained were satisfactory and the extension of this work includes the hardware implementation of the sensor and the application of the measurement-based approach to quality control of spray droplets in agriculture.

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REFERENCES

[1] R. Mulley, *Flow of industrial fluids: theory and equations*. CRC Press, 2004.

[2] A. Akers, M. Gassman, and R. Smith, *Hydraulic Power System Analysis*. Broken Sound Parkway: CRC Press, 2006.

[3] J. xian Zhang, Y. tao Ju, S. qiang Zhou, and C. Zhou, “Air-pasty propellant pressure drop and heat transfer through round pipe,” in *2008 Asia Simulation Conference - 7th International Conference on System Simulation and Scientific Computing*, Oct 2008, pp. 1282–1285.

[4] L. E. Bode and S. M. Bretthauer, “Agricultural chemical application technology: a remarkable past and an amazing future,” *Transactions of the ASAE (American Society of Agricultural Engineers)*, vol. 51, no. 2, p. 391, 2008.

[5] P. Chueca, C. Garcera, E. Molto, and A. Gutierrez, “Development of a sensor-controlled sprayer for applying low-volume bait treatments,” *Crop Protection*, vol. 27, no. 10, pp. 1373–1379, 2008.

[6] S. Han, L. L. Hendrickson, B. Ni, and Q. Zhang, “Modification and testing of a comercial sprayer with pwm solenoids for precision spraying,” *Applied Engineering in Agriculture*, vol. 5, no. 17, pp. 591–594, 2001.

[7] F. H. R. Baio and U. R. Antuniassi, “Sistemas de controle eletrônico e navegação para pulverizadores (electronic control and navigation systems for sprayers),” in *Tecnologia de Aplicação para Culturas Anuais (Application Technology for Annual Crops)*, U. R. Antuniassi and W. Boller, Eds. Passo Fundo: Aldeia Norte, 2011.

[8] P. E. Cruvinel, D. Karam, and M. G. Beraldo, “Method for the precision application of herbicides in the controlling of weed species into a culture of maize,” in *VII Simpósio Internacional de Tecnologia de Aplicação (International Symposium on Application Technology)*. Uberlândia,MG: SINTAG, 2015.

[9] K. R. Felizardo, H. V. Mercaldi, P. E. Cruvinel, V. A. Oliveira, and B. L. Steward, “Modeling and model validation of a chemical injection sprayer system,” *Applied Engineering in Agriculture*, vol. 32, no. 3, pp. 285–297, 2016.

[10] Y. Suzumura and P. E. Cruvinel, “Análise de qualidade da eficiência da pulverização agrícola com processamento de imagem e rede neural (quality analysis of crop spray efficiency with image processing and neural network),” *Sinergia*, vol. 6, no. 2, pp. 129–137, 2005.

[11] R. A. Kohl, “Drop size distribution from medium-sized agricultural sprinklers,” *Transaction of the ASAE*, vol. 17, no. 4, pp. 690 – 693, 1974.

[12] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers*, 6th ed. New York: W. H. Freeman, 2007.

[13] L. Thévenin, “Extension de la loi d’ohm aux circuits électromoteurs complexes (extension of ohm’s law to complex electromotive circuits),” *C. R. des Séances de l’Academie des Sciences*, 1883.

[14] L. Thévenin, “Sur un nouveau théorème d’électricité dynamique (on a new theorem of dynamic electricity),” *Annales Télégraphiques*, 1883.

[15] J. Brittain, “Thevenin’s theorem,” *Spectrum, IEEE*, vol. 27, no. 3, pp. 42–, 1990.

[16] D. Johnson, “Origins of the equivalent circuit concept: the current-source equivalent,” *Proceedings of the IEEE*, vol. 91, no. 5, pp. 817–821, 2003.

[17] S. P. Bhattacharyya, L. H. Keel, and D. Mohsenizadeh, *Linear Systems: A Measurement Based Approach*, ser. Springer Briefs in Applied Sciences and Technology. Springer, 2013.

[18] N. Mohsenizadeh, H. Nounou, M. Nounou, A. Datta, and S. P. Bhattacharyya, “Linear circuits: a measurement-based approach,” *International Journal of Circuit Theory and Applications*, vol. 43, no. 2, pp. 205–232, 2013.

[19] P. E. Cruvinel, V. A. Oliveira, K. R. Felizardo, and H. V. Mercaldi, “Bancada automatizada para ensaios e desenvolvimento de pulverizadores de agrotóxicos, aplicadores de fertilizantes líquidos e maturadores em culturas agrícolas sob manejo baseado em agricultura de precisão (automated bench for testing and development of pesticide sprays, liquid fertilizer applicators and ripeners in agricultural crops under precision agriculture based management),” in *Agricultura de Precisão: um Novo Olhar*. São Carlos, SP: Embrapa Instrumentação, 2011, pp. 96–100.

[20] P. E. Cruvinel, V. A. Oliveira, H. V. Mercaldi, E. A. G. Peñaloza, and K. R. Felizardo, “An advanced sensors-based platform for the development of agricultural sprayers,” in *Sensors and Applications in Measuring and Automation Control Systems*, S. Y. Yurish, Ed. International Frequency Sensor Association, December 2016, pp. 181–204.