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DEVELOPMENT OF AN ELECTRONIC SYSTEM FOR MONITORING FLUID FLOW (PITOT TUBE)

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Abstract. *This work proposes the development of an electronic system to measure pressure, fluid velocity and fluid flow in several experimental applications. It consists in an electronic system, with low cost and easy installation on any equipment. The operating principle is similar to Pitot tube, which uses two pressure taps for calculating the fluid velocity. The first pressure tap is in the flow direction and measures the sum of the pressure and fluid velocity (total head). The second one is perpendicular to the flow and measures only pressure head. The sensors used in this work have a pressure range from 0 to 4 kPa, however according to the experimental application others sensors can be used. A micro-controller receives an electrical signal emitted by the sensor and, using a calibration curve, provided by the manufacturer, calculates the equivalent pressure to that signal. Then, using Bernoulli's equation, the micro-controller calculates the pressure and fluid velocity and prints such data on LCD. The device developed in this work was previously tested in laboratory to ensure that it was calibrated and then it was applied in an industrial process to measure pressure, fluid velocity and fluid flow to aerate organic compost piles. The obtained results were used to design a new aeration system, which was later adopted by the company to optimize the production of organic compost.*

Keywords: *electronic system; pitot tube; fluid velocity and pressure.*

1. INTRODUCTION

Data acquisition systems are used to control industrial processes and measure temperature, pressure, fluid velocity, fluid flow, moisture, gas emissions, among others. These data are used for safety, control, optimization and development of new projects.

Pazos (2002) comments that for data acquisition there are two components that must be observed: the sensors and transducers. The sensor is the sensitive part while the transducer has an electronic circuitry responsible for receiving and transmitting a signal generated by the sensor. The main characteristics of sensors are: the range, resolution, sensitivity and linearity, these characteristics should be selected according to the application. In this work it was studied pressure sensors to develop an electronic system capable of measure pressure, fluid velocity and flow rate.

Pressure measurement is very important in industry. From pressure others parameter can be controlled, estimated or calculated, such as: volume, density, temperature, flow rate, phase change, among others (Cassiolato, 2010).

The use of electronic sensors facilitates pressure measurement and control and data can be saved or accessed in real-time via a computer. Several companies provide solutions for measurement (sensors, data acquisition systems and softwares), but such products has usually high cost. However, low-cost electronic sensors are available for purchase. Typically, they are easy to assemble and install and manufacturers provide its calibration curve.

In this sense, this paper presents the development and assembly of device for monitoring pressure and fluid velocity. The equipment is basically a Pitot tube. The device has been tested in laboratory and in an industrial application. Results were compared to data monitored by a commercial Pitot tube.

2. METODOLOGY

A Pitot tube is a device to measure pressure, fluid velocity and fluid flow. There are many applications for Pitot tubes: from aircrafts to industrial process.

In industry, the velocities being measured are often those flowing in ducts and tubing where measurements by an anemometer would be difficult to obtain. In these kinds of measurements, the most practical instrument to use is the Pitot tube. It can be inserted through a small hole in the duct with the pitot connected to a U-tube water gauge or some other differential pressure gauge for determining the velocity inside the ducted wind tunnel.

The Pitot tube operating principle is based on the difference in fluid pressure when the flow is subjected to a small obstacle (stagnation pressure), as shown in Figure 1. Measuring the static and stagnation pressure of the fluid it is possible to calculate the fluid velocity using Bernoulli equation (Çengel, 2007).

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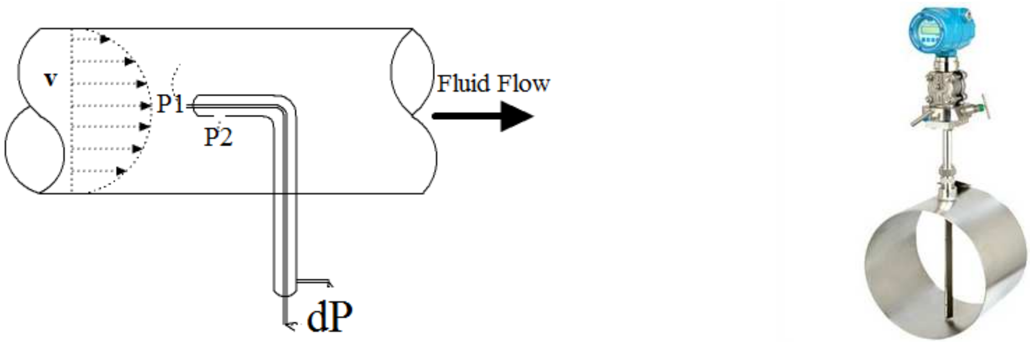

a) b)

Figure 1. Pitot tube. a) Pitot tube scheme. b) Commercial Pitot tube in a duct

There are a lot of commercial Pitot tubes. Some equipment are more expensive and has data acquisition system that allows save or monitoring data in a computer, still there are cheaper ones whose data is shown in digital display (Fig. 1b).

This work proposes the development of a cheaper Pitot tube that allows save and monitoring data on a computer. The costs of construction were less than commercial equipment with digital display. It was estimated around U$ 75,00 for the construction of the entire device.

Basically, the device measures the stagnation and static pressure and show experimental data in a digital display (pressure and air velocity). Data can even be presented in form of graphs and saved on a computer. The equipment size was reduced, allowing its easy installation in ducts of any diameter.

The system is divided into sensors, acquisition circuit, display and data transfer, as shown in Fig 2.

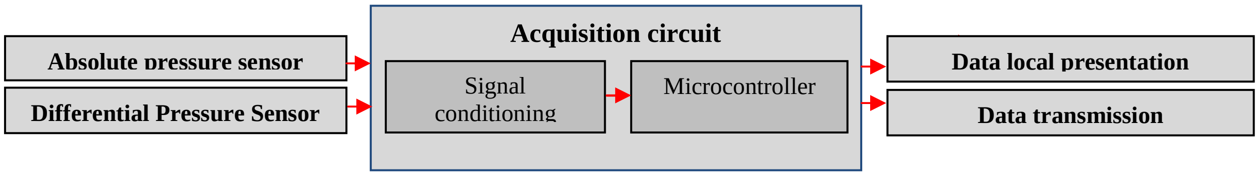

Figure 2. Block diagram of the system for measuring the pressure and air velocity

After analysis of several commercial catalogs about pressure sensors models, the selected sensors were MPxx5004 series. This series were developed by the company *Freescale* and combines a resistive element type strain gauge sensor with high accuracy and signal quality. The sensor output is amplified and has high ratio between the inlet pressure and the output voltage. This is important for the acquisition circuit, reducing noise and cost of construction. The operating temperature range is about 10°C to 60 ºC. One sensor is about U$ 14,00 and it is available in various configurations for pressure input as shown in Fig. 3. According to the application, a sensor can be chosen.

a) b) c)

Figure 3. MPxx5004 Series Sensors. a) Differential pressure sensor with two inputs. b) Absolute pressure sensor. c) Differential pressure sensor with ambient pressure input.

The sensor operation is based on strain gauge deformation due to pressure variation, this deformation is converted by an electromechanical system, and thus the output is an electrical signal which can be measured by an acquisition system. A calibration curve relating to the output (electrical signal) and input (pressure difference) was provided by the manufacturer. The structure of the sensor presented in Fig. 3c and the calibration curve provided by the manufacturer are shown in Fig. 4.

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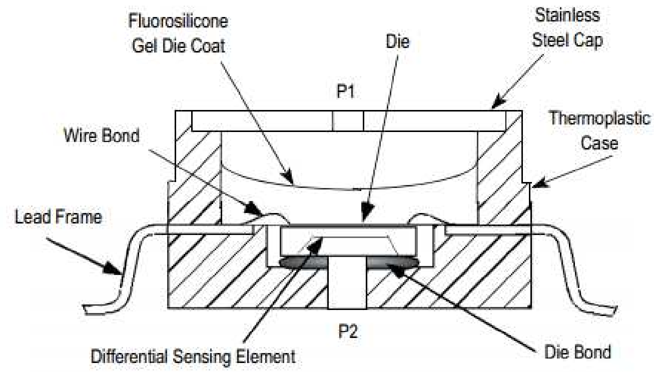

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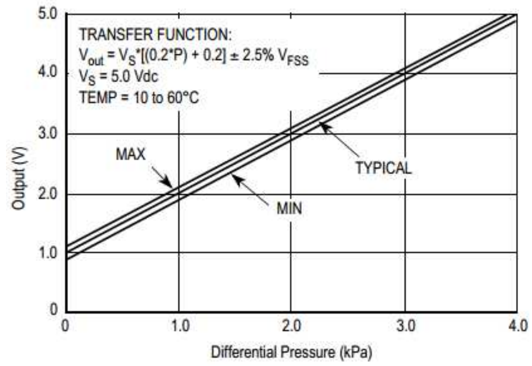

b)

Figure 4. Details of sensors presented in Fig. 3c:
a) Sectional drawing of the sensor b) Calibration curve (Freescale, 2009)

Based on preliminary tests performed with the sensors described above, two of them were selected. The MPXV5004DP was used as a Pitot tube to measure the differential pressure in a duct and the MPXV5004GC7U sensor was used to determine the absolute pressure. The positioning of the sensors in a duct is shown in Fig. 5.

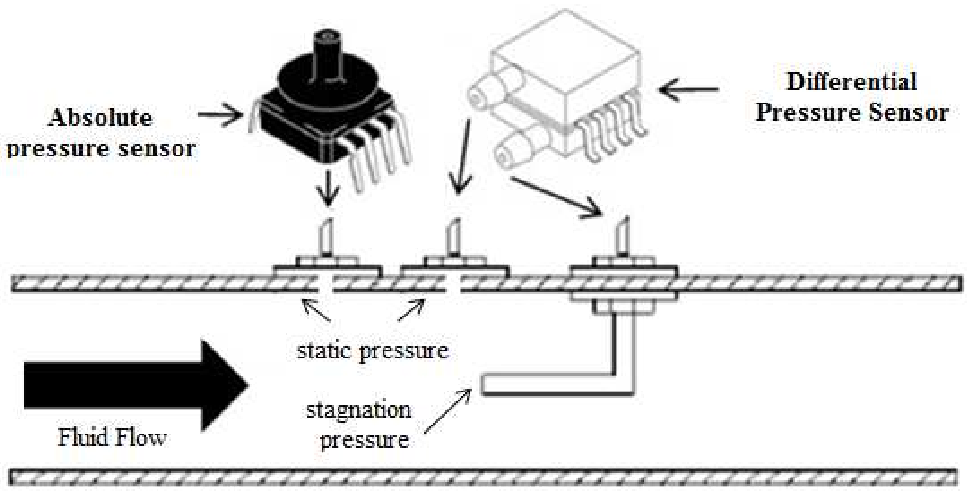

Figure 5. Schematic of the device developed for measuring air pressure and velocity. (Figueira Jr, 2012).

The correct position of the sensors in a duct is in a region where laminar flow is available, thereby avoiding uncertainties in pressure and fluid velocity readings.

After the choice and adaptation of sensors in a duct it was developed an acquisition circuitry and software to process the signals provided by them. Filters were used to convert analogic signals to digital.

The time acquisition and signal conversion are adjusted in 100ms. A second digital filter was installed and based on the technique of weighted averages it was used to calculate the absolute pressure value.

An PIC18F4550 microcontroller developed by Microchip Inc was also used. Among its many features, it adds to the electronic system high processing capacity, wide range of operating voltage, analog to digital converter (ADC) of 10bits, USART and USB connection, allows data transmission to a computer, it has sufficient quantity of pins for connecting an LCD display, among others. With respect to the operating voltage, the PIC is very important because the circuit was project to work with batteries.

Based on experimental measured values and Bernoulli's equation (Eq. 1), fluid velocity can be calculated as presented in Eq. (2).

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 \qquad (1)$$

It was considered incompressible and laminar flow and based on the differential pressure measured with the differential pressure sensor, fluid velocity was calculated (Eq.2).

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$$V = \sqrt{\frac{2(\Delta P)}{\rho}} \tag{2}$$

The fluid velocity and pressure after calculated are shown locally in a liquid crystal display (LCD) connected to the microcontroller. Through an USB port data are transferred in real-time to a computer. In this sense, the microcontroller adopted in this work provides data transfer, flexibility, and power supply at the same connection, which reduces power consumption of battery. Unfortunately, a wired transmission is needed so computer must be closer to the developed device.

To calibrate and analyze the performance of the device experimental tests were conducted in Heat and Mass Transfer Laboratory (LTCM), College of Mechanical Engineering of Federal University of Uberlandia (UFU). To evaluate the mechanism proposed in this work, it was installed in a duct, where it was possible to control the fluid flow through a fan as shown in Fig.6. The pressure and fluid flow were compared with data measured by a commercial micromanometer (Alnor - AXD 550).

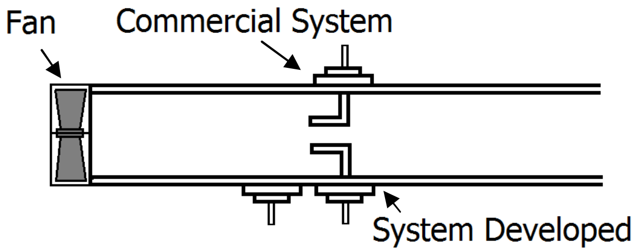
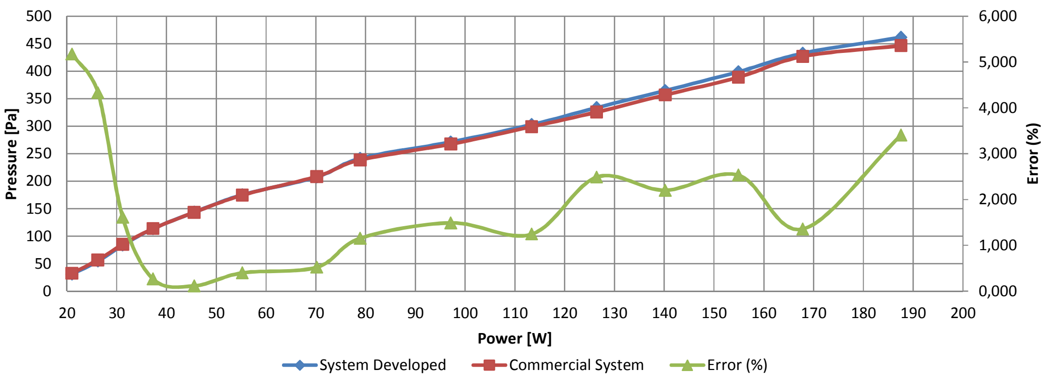


Figure 6. Bench to evaluate the proposed system

Figure 7 shows a comparison between pressure and fluid flow measured for both devices. The relative error between measured signals is also presented.



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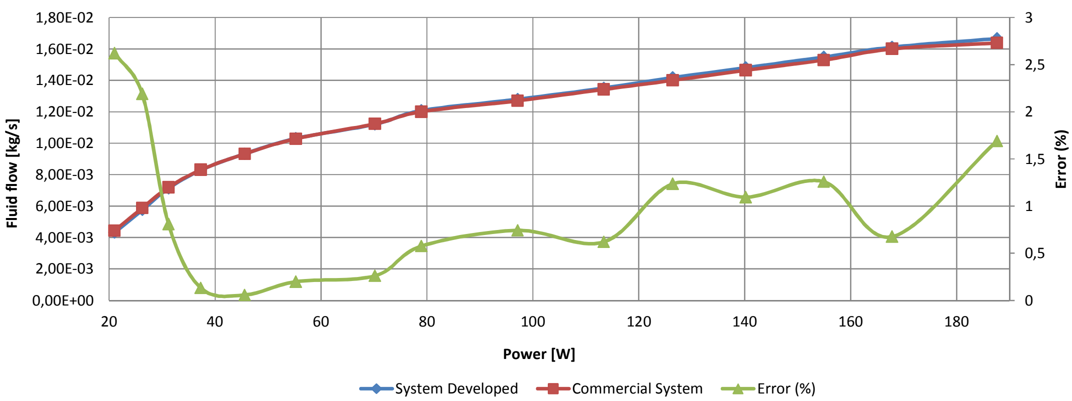

b)

Figure 7. Data measured with the experimental device when compared with a commercial manometer: a) Pressure and b) Fluid flow.

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In Figure 7 it is observed a good agreement between experimental data. The relative error obtained can be explained by the assembling of the device in the duct. As can be seen in Figure 5, with the device the static pressure was measured at the tube surface. In commercial sensors this value is measured near the stagnation pressure in the center of the duct.

Finally it was noted that the device is quite sensitive to pressure variations in the duct and that the relative error tends to decrease when the static pressure is measured at the same position of the duct with both equipment.

3. CASE STUDY: ORGANIC COMPOSTING

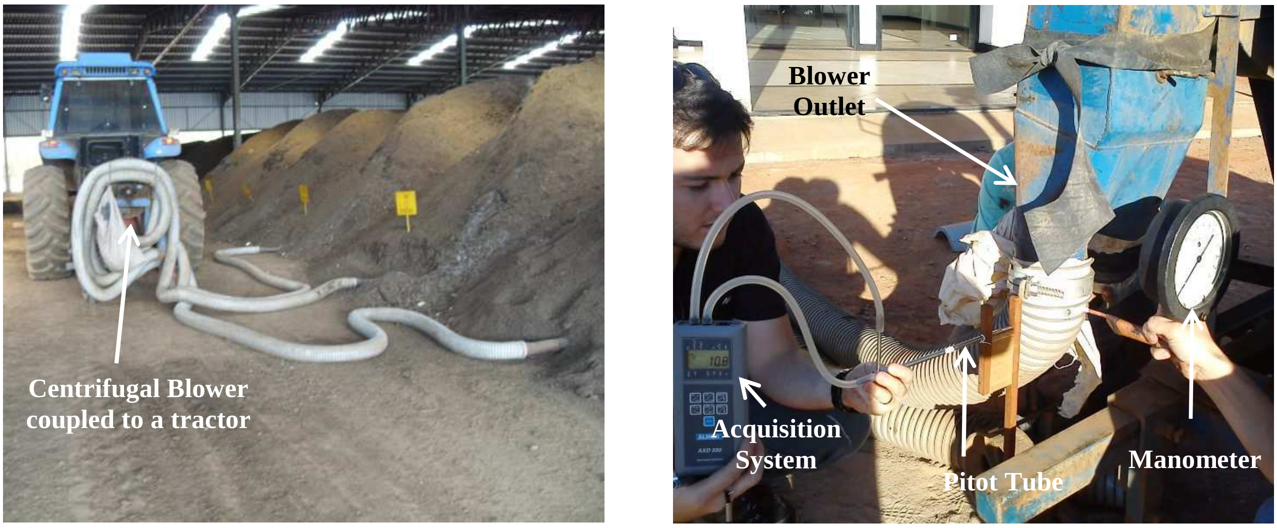
After several laboratory tests the device was validated and then applied in the design of an aeration system for organic composting.

The correct disposal of organic wastes from urban centers, industries and animal husbandry is the organic composting. In the last decades, organic waste used to be destined to dumps, landfills and controlled landfills, along with all the garbage produced, causing damage to the environment. Therefore, composting can be considered a sustainable solution to reduce organic wastes generated by humanity. This is an old process, performed by humans since the beginning of agriculture, taking advantage of organic wastes to improve soil quality. Nowadays this process has been associated with the organic waste treatment. Thus, human action is needed to accelerate the decomposition, by the handling of various organic materials and the automation of the compost process.

In developed countries composting is a very common practice. In the United States and Germany many companies invest in the compost plants automation, to accelerate and optimize the process. On the other hand, in Brazil, composting in an industrial scale is still an outdated practice and it is based on machines and technologies from agricultural sectors (Schalch et al., 2002).

The organic composting industry analyzed currently has 48 compost piles that are aerated by a blower moved by the engine of a tractor. The standard practice is to aerate four windrows at a time as showed in Fig. (8a). The blower coupled to the tractor is turned on for 5 minutes and, after that, it is turned off and the tubes are unplugged and relocated to aerate other four compost piles. The aeration process is performed only during the day and depends on the employees to operate the tractor and relocate the tubes.

Experimental tests were performed to verify the mechanical characteristics of the blower used in the company’s standard practice (Fig. 8b). The goal is to replace the equipment for an equivalent electric blower that could be driving by an electronic system. In this case the mechanical characteristics are the flow rate (m³/min), pressure (mmca) and the power (CV). During the experimental procedure were used a Pitot tube, a pressure gauge, a caliper, an AXD 550 Micromanometer acquisition system, tube and a microcomputer to determine the mechanical characteristics of the blower moved by a tractor.



a) b)

Figure 8. Aeration in organic compost piles a) Blower coupled to a tractor and organic compost piles; b) Experiment to determine the mechanical characteristics of the blower.

The device was development to get process parameters (pressure and flow) easily. These parameters were necessary to investigate the companies standard system characteristics, these data will be used to sizing a network assuring air demand for process will be subsequently used to gauge the new system and also to find flaws in the tubes assembly. The main features of the device required to meet the process are: low cost, robustness, and is able to get the data in real time.

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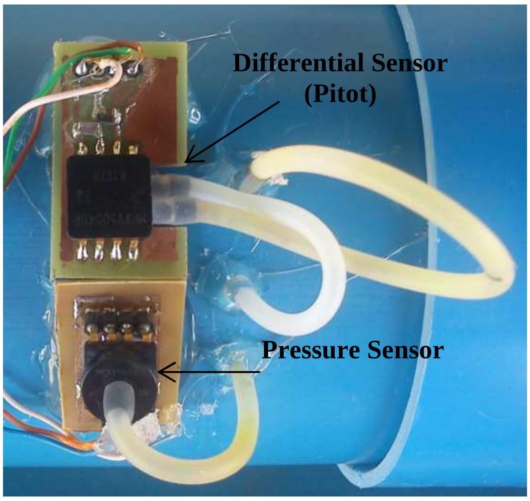
In this case the developed device has plugged on ventilation ducts, facilitating the acquisition data. The Fig. 9 shows the details of the assembly.

a)



b)

Figure 9. Details of the Pitot tube assembly in the pipelines. a) Device in operation and b) details of the assembly.

The device was able to acquire the values of pressures at a low cost, real-time, allowing easy and practice assembly, facilitating equipment use anywhere the data should be determined. Its predominant features were the possibility to mount inside the aeration pipe, easy assembly and remove after the acquisition of the data, allowing a diagnosis is made on the pipe at the same time the user reads the data printed on the device screen.

Based on device obtained data, SAFA was sized. Four blowers were installed in order to aerate eight compost piles. Only a blower is turned on each time and in the first test it stays on for ten minutes. Considering eight compost piles, a complete cycle of aeration lasts forty minutes. After this time, the aeration cycle restarts. It works twenty-four hours a day and the blower operation time can be adjusted according to the compost, levels of temperature and oxygen in the compost piles.

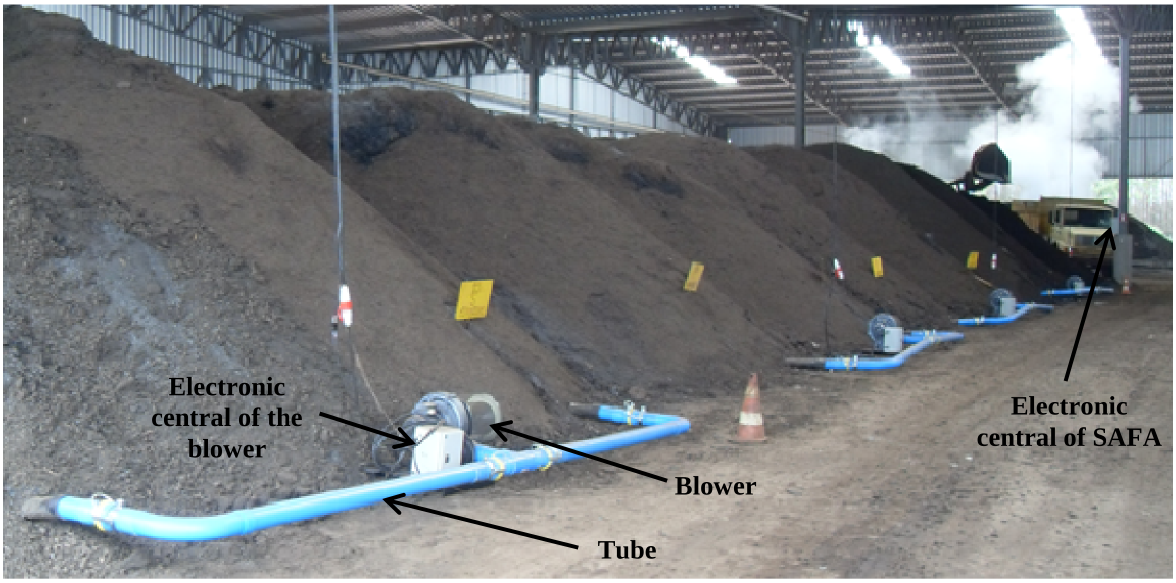


Figure 10. SAFA installed in the compost shed.

Thus, to identify the correct time of aeration of the piles, this work proposes an analysis of the oxygen and temperature levels during three compost cycles. It was considered the same compound and each cycle lasted thirty days on average. Eight compost piles have been aerated and each one had thirty meters long and three meters high.

The blowers were turned on sequentially, one by one, for a period of time set in the electronic system. In the first cycle a blower is turned on for 5 minutes, after that time, it turns off and remains in standby mode for 5 minutes, then when the next blower is turned on. A complete aeration cycle was standardized in 40 minutes. In the second cycle it was set an aeration time of 7 minutes and 3 minutes in standby mode. In the last one, 10 minutes of aeration and 2 seconds in standby mode.

The oxygen and temperature levels were measured in the middle of the pile, two meters above the ground. The gas analyzer Testo 350S was used in the experiments. The maximum and minimum values of oxygen and temperature measured in each cycle are shown in Table 1.

Table 1. Maximum and minimum levels of oxygen and temperature measured during each compost cycles.

Aeration Time (minutes)	Levels of Oxygen and Temperature	
	Maximum	**Minimum**
5	12.2% of O_2 and 65.1°C	8.52% of O_2 and 61.1°C
7	16.1% of O_2 and 69.3°C	11.7% of O_2 and 60.4°C
10	19.6% of O_2 and 78.8°C	14.7% of O_2 and 77.0°C

In first cycle it can be seen that 5 minutes of aeration was insufficient. The oxygen level was less than 10%, which may lead to an anaerobic compost process, considered undesirable for some researchers as Diaz et al., (1982), Gomes and Pacheco (1988) and Fernandes (1999).

Meanwhile, when the blowers were turned on during 7 and 10 minutes, the oxygen levels are presented in a range recommended for the composting of organic waste that varies from 14 to 17% according to Diaz et al. (1982). Some authors state that the temperature should not exceed 70°C because it could cause the death of microorganisms. Thus, 10 minutes of aeration could not be considered an appropriated time for composting. It was expected that the excess of oxygen could decrease the temperature of the windrow due to death of microorganisms. However, it did not happen. Therefore, during this research, it was concluded that 7 or even 10 minutes of aeration could be applied to accelerate the compost process, reducing the production time.

According to the company rules, the compost process ends when the cycle reach 30 days and the compost humidity is around 30%. Therefore, the moisture content of the windrows was evaluated after 30 days to compare the performance of the blower coupled to the tractor and the electronic system proposed in this work called SAFA.

It can be seen that the moisture measurement in windrows with SAFA is fairly less than that identified in standard practice. This means that the composting cycle could have been stopped before 30 days provided by standard practice. Thus, SAFA provides a regular oxygenation of the compost piles, thereby reducing the moisture content, increasing the screening rate of the compost and finally reducing the production cycle. Based on these parameters, SAFA is shown as a promising tool for production of organic fertilizers.

4. CONCLUSIONS

This work presented the development and assembly of a device for monitoring pressure and fluid velocity, basically a Pitot tube. The device was tested and validated in laboratory where it proved to be reliable, robust and easy to use. Subsequently the device was applied in an industrial process where it allows the design of an automated aeration process of organic compost piles, namely SAFA, in order to accelerate and optimize the production of bio fertilizers in a Brazilian industrial plant.

According to the results, it was concluded that SAFA tends to reduce the time demanded for the organic compost production in at least three days, since promotes a faster pile drying. It represents an 8% increase in the company’s annual production. Furthermore, the system increased oxygen levels in the compost windrows, favoring aerobiosis. Therefore, the continuous aeration cycle (24 hours per day) allows faster reduction in the moisture content of the compost and higher levels of oxygen and temperature into the windrows. Furthermore, the automated aeration system (SAFA) provides a lower operating cost when compared with the old ventilation system.

5. ACKNOWLEDGEMENTS

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