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CONSTRUCTION OF A 1 TO 5 SCALE VERTICAL INTERMITTENT COFFEE DRYER PROTOTYPE

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Abstract. *Drying is a crucial step in the coffee production process, consisting of removing moisture from the beans to preserve them and guarantee their quality and flavor. Coffee dryers are large equipment, usually located in the field, so drying tests require time and entail high fuel costs, in addition to requiring large amounts of grain samples. A scaled equipment in a laboratory allows further studies of the drying process of coffee beans. In view of this, a prototype of an intermittent vertical coffee dryer was built on a scale of 1 to 5, with the objective of enabling tests and applications in the laboratory. The prototype, even being built on a reduced scale, presented all the functionalities of a dryer on a commercial scale. This was instrumented with a temperature sensor and an actuator responsible for feeding the thermal system. Data acquisition was performed by microcontroller. The data obtained were sent using serial communication between the microcontroller and the LabVIEW® software. The results show that a prototype was obtained that allows optimizing coffee drying, aiming at reducing fuel consumption and obtaining better product quality. The analyzes were carried out through readings of the temperature graph, traced using the LabVIEW® software.*

Keywords: *Coffee Dryers, Manufacture of Prototypes, Temperature Sensors, Microcontrollers.*

1. INTRODUCTION

The competitiveness of the agro-industrial sectors and the growing production of coffee in Brazil, which keeps the country as the world's largest producer of the grain, challenges producers to improve cultivation techniques and processing processes to meet the demanding quality standards of the market (Nakazone & Macchinone, 2004).

According to Borém et. al. (2007) the international consumer market has as its main requirement the production of quality coffee, valuing the sensory, organoleptic and hygienic attributes of the product, in addition to aspects related to environmental protection and social appreciation. These are the biggest obstacles encountered by producers to conquer new markets.

Lacerda Filho et al. (2001) evaluated the quality of coffee by comparing the results of the analyzes of beverages obtained from a product contaminated by microorganisms with beverages obtained from a healthy product, verifying that all fermented or rotten products had a lower quality beverage. Thus, in addition to crop care, it is necessary to establish a faster and more efficient drying process, providing better organoleptic quality to the product.

Drying is an important and costly step in the grain production chain and in the case of coffee, compared to other grains, it is more difficult to perform due to the high initial moisture content. Care must be redoubled, especially after harvesting, as the high concentration of sugar present in the mucilage, in addition to the high-water content, approximately 60% on a wet basis (w.b.), make the rate of deterioration high and may compromise the quality (Jasper et al, 2007).

Drying yards are used by most producers. However, the low drying rate, the exposure of the product to biological agents and the possibility of occurrence of unfavorable climatic conditions, can negatively impact the quality (Borém et. al., 2007).

Coffee can undergo major changes in its commercial value due to the quality presented, and its price may be gradually reduced or increased according to the classification levels (Almeida et. al). The use of mechanical dryers or the combination of drying yards and mechanical dryers can, when used correctly, contribute to obtaining quality coffee for export (Lacerda Filho, 2001).

The quest for quality and cost reduction has required producers to control and monitor the drying processes. The energy consumption, performance and temperature of a dryer are parameters that have been given great emphasis when choosing an effective drying system (Jasperet al, 2007).

In order to meet the need to improve the drying processes demanded by producers, this work carried out the construction of a prototype of a cross-flow intermittent vertical coffee dryer, which will be used to carry out tests in laboratories and in the future to optimize the process coffee drying.

To prove the proper functioning of the prototype, the temperature values were acquired through a micro controlled system and the data were sent to LabVIEW® through serial communication. With the obtained data vector, the drying air temperature graph was plotted as a function of time.

The construction of the intermittent vertical coffee dryer prototype will enable the validation of the work in practice. This prototype can generate new projects related to the drying process, ranging from improvement in thermodynamics to optimization with the application of control and automation techniques, aiming at obtaining an efficient drying process and avoiding the occurrence of losses due to misuse of the dryer.

According to Silva, JS et. al. (2001), the use of mechanical dryers presents several advantages in relation to the drying yard. The construction of more energy efficient dryers, which provide a final product of good quality, must be seen as a great technological effort, thus reducing drying costs and increasing the competitiveness of Brazilian coffee in the international market.

The contribution of this work is to provide a tool that makes it possible to make improvements in drying processes and, consequently, contribute to obtaining quality coffees, through the construction of a coffee dryer in reduced size, for carrying out research in an academic laboratory.

2. COFFEE DRYING PROCESS

Drying is one of the preprocessing stages of agricultural products whose purpose is to remove part of the water contained in them. It is defined as a simultaneous heat and mass (moisture) transfer process between the drying air and the product, respectively. Moisture removal must be at such a level that the product is in balance with the environment where it will be stored and must be done in a way to guarantee the quality of the product (Martin, 2009).

The moisture content of grains is an important factor that contributes to the growth of fungi, one of the main causes of reduced quality of agricultural products. Moisture-related problems occur to a large extent when coffee is dried on the patio. According to Sampaio (2004) this type of drying is an operation that presents problems caused by the variability of climatic conditions, therefore, difficult to be controlled. Even so, the vast majority of coffee growers use the yard as the only drying stage.

Depending on the climate and/or humidity of the coffee, the proliferation of fungi and fermentation can occur during drying on the patio, because on cold days and with high relative humidity, the loss of moisture from the beans is low, causing the coffee remains for up to 20 days in the yard, reducing its quality. Another problem with drying on patios occurs when the coffee has a reduced percentage of moisture and there is rainy weather, which means that it may lose quality and, consequently, its price is reduced (Campos, 1998).

With the existing problems during the drying of beans on the patio, the correct use of artificial drying, in mechanical dryers, is a procedure of fundamental importance for the grain producer to produce quality coffee today (Martins, 1997).

The consumer market demands quality coffee that has indispensable organoleptic properties. These properties are related to the processing of the product, which the drying process has great influence (Vieira, 1994).

Obtaining a quick and well-conducted drying through mechanical dryers can eliminate all the problems inherent to drying in the yard. But an incorrectly performed artificial drying could even reduce the quality of the coffee and the commercial value of the product. In view of the above, it is clear the need to implement projects for automation and control of drying processes, which will be provided by the coffee dryer prototype built.

Coffee drying should not be slow or forced with high temperature peaks, thus requiring adequate temperature control, so as not to compromise the product.

2.1 Operation of coffee dryer

The coffee dryer used in this project is a cross-flow intermittent vertical, with an indirect fire furnace. The schematic of this dryer can be seen in Figure 2.1.

This is one of the most used models of dryers for drying coffee. A characteristic of this dryer is the presence of a rest chamber, which allows the process to become intermittent.

In this type of dryer, the first step is to fill the silo or rest chamber through the bucket elevator. The coffee is stored in this chamber and, by gravity, goes down to the drying chamber where it receives high temperature air. Then, the coffee falls from the bottom of the drying chamber, with constant flow, and is received by the pre-cleaner, which sieves the impurities and moves the product to the bucket elevator, which returns with the coffee to the resting chamber, closing the loop. This drying becomes intermittent, interspersed with periods of rest (Vieira, 1994).

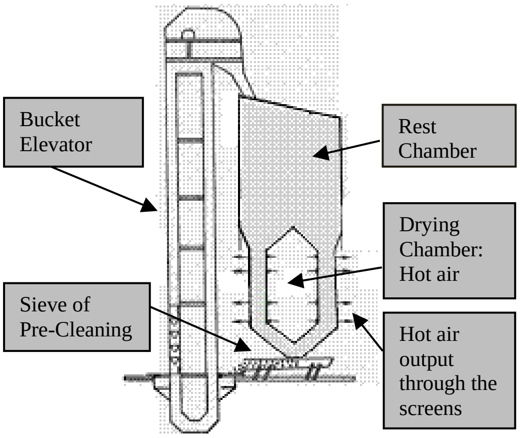

Figure 2.1 – Intermittent vertical commercial dryer scheme (Source: adapted from Vieira, 1994)

The great advantage of this dryer is that during the time the grain remains in the resting chamber, the drier fruit absorbs moisture from the less dry fruit, making the mass of the product homogeneous. Another important point is that at this moment water is transferred to the periphery of the coffee, facilitating the removal of moisture in the next stage of drying (Lacerda Filho et. al., 2001).

Figure 2.2 illustrates a commercial scale intermittent cross-flow vertical coffee dryer. In Figure 2.2 the parts of the dryer are shown, as explained in the sketch in Figure 2.1, including the furnace.

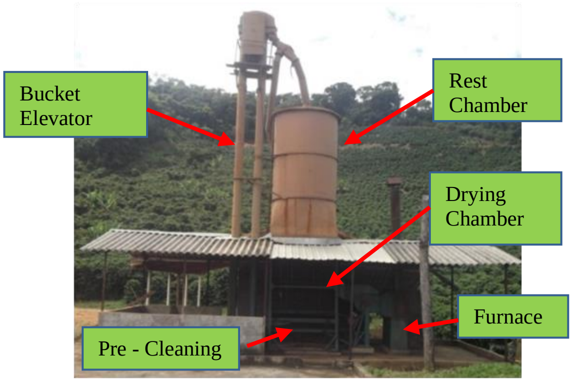

Figure 2.2 – Commercial intermittent vertical coffee dryer (Rural Property in Abre Campo MG)
(Source: From the author, 2013)

The air heating process takes place in the furnace, whose fuel is the straw itself from the coffee husking. Figure 2.3 shows the firebox and burner. The burner is an electromechanical system with the function of feeding the furnace, it has an endless thread at the bottom of the hopper that injects the straw.

Inside the furnace there is a heat exchanger between the cold air coming from the environment and the plates at high temperature, forming the heated air. The heated air is sucked in by a turbine and transported into the drying chamber and, upon exiting to the environment, passes between the coffee beans that descend between two screens.

Figure 2.3 – Image of the commercial coffee straw furnace and burner (Rural Property in Abre Campo MG) (Source: From the author, 2013)

The furnace uses indirect fire, as the coffee drying air is isolated from fire and smoke by the internal structure, that is, by the heat exchanger. This model is more suitable, as it does not affect the quality of the product with the gases from the burning of fuels, in addition to being safer, as it prevents the coffee from burning with fire sparks.

The intermittent vertical dryer must operate at temperature ranges from 80°C to 120°C, values suitable for the coffee drying process (Lacerda Filho et. al., 2001). To start the drying process, the coffee must have reduced moisture because this type of dryer does not work properly with wet beans and with little fluidity. This initial reduction in moisture can be carried out in concrete terraces, since the probability of quality loss is small (even the yard is not efficient in drying the coffee, it can be important to reduce the humidity in the pre-drying due to the low cost, of course subject to climatic conditions and due care), in static dryers or in rotary dryers.

After harvesting, the coffee bean has a moisture content of around 60% (w.b.) and can remain on the drying terrace until it reaches a percentage between 25% and 30% (w.b.) reach humidity between 11% and 13% (w.b.), which is suitable for storage.

According to Campos (1998), if the coffee is dried only in terraces, drying can take 15 to 20 days, due to the low percentage of moisture loss to the environment.

The intermittent vertical dryer has the advantage of accelerating the process, because as the humidity is already reduced, the coffee can be dried at high temperatures. The difference between the intermittent vertical dryer and the concrete terrace in terms of drying time is that the first takes a few hours while the second takes a few days to complete the process.

Silva and Cardoso Sobrinho (2001) carried out a study considering two cases: (1) pre-drying in a rotary dryer combined with an intermittent vertical dryer; (2) total drying in rotary dryers. It has been proven that combined drying has lower energy consumption, which makes the use of intermittent vertical dryers combined with rotary dryers an interesting option.

In the case of rotary or static dryers, as drying normally starts with high humidity values (around 60% bu), drying temperatures must be lower than those of vertical dryers. The temperature control requirement is more critical than in the vertical intermittent dryer, as the process is continuous. Care must be taken not to exceed the temperature in the grain mass. Coffee must be dried at 30 to 40°C in the first ten hours of drying, which can be gradually increased to 45°C (Campos, 1998).

3. CONSTRUCTION OF THE COFFEE DRYER PROTOTYPE

The coffee dryer prototype built was of the cross-flow intermittent vertical type, with an indirect fire furnace, based on the model described by Vieira, 1994.

The construction of the prototype aimed to make it possible to carry out tests and practical projects in laboratories, even in places that do not have coffee dryers. For this, the scale was reduced to the point that it did not affect the operation of the dryer. In this case, the scale defined for the construction was 1 to 5. To facilitate the movement of the equipment, a metallic structure with wheels was built so that the prototype could be placed on it.

An advantage of this work is that materials and equipment such as motors, bearings, belts, worms, clay bricks were reused, thus obtaining a low-cost project.

The construction of the prototype followed the same structure as the dryer shown in Figures 2.2 and 2.3 in the previous section. Being divided into the following parts: silo, bucket elevator, pre-cleaning, drying chamber, turbines, furnace and burner.

The function of the silo is to store the coffee and also, according to Vieira (1994), to make the dryer intermittent. It is an adaptation of the continuous cross-flow dryers used for cereal drying.

Usually the most used coffee dryers have a silo with 4 to 5 rings and these are screwed one over the other. In the case of this prototype, the rings were welded due to its small dimensions and the fact that there was no need to disassemble the equipment.

In cylindrical silo dryers, the first ring has the function of converting from a square shape to a cylindrical shape. The first ring connects the square drying chamber to the cylindrical silo. In the case of this project, it was decided to build a hexagonal silo, so the first ring converted from a square to a hexagon.

The drying chamber is where the coffee receives hot air from the furnace. In the construction, perforated screens were used for the passage of hot air from the interior of the chamber to the outside region, passing between the coffee beans that descend between these screens.

The furnace built was indirect fire, its outline can be seen in Figure 3.1.

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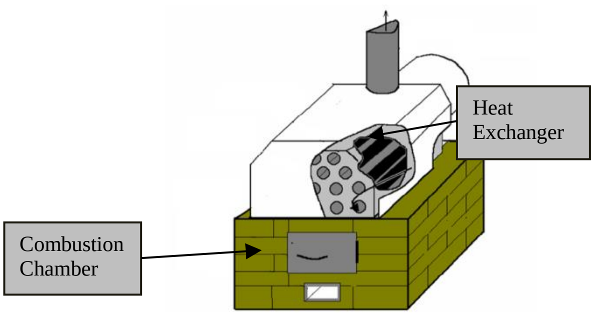

Figure 3.1: Indirect Fire Furnace (Source: Gessi De Oliveira, 2011)

In the cutout detail, the heat exchanger between the air and the iron structure can be seen. This is where the dryer air is heated.

In Figure 3.1, the combustion chamber can also be seen, where fuels are burned, releasing thermal energy to the heat exchanger. This furnace was built surrounded by refractory bricks that help conserve heat. In the case of the prototype, the fuel used was coffee straw and wood sawdust.

The elevator is used to transport the coffee to the silo. In the case of this project, the elevator was built according to the commercial standard, that is, with buckets screwed onto a conveyor belt, allowing the coffee to be transported vertically.

The intermittent vertical dryer has two turbines: a large one that drives the air from the furnace heat exchanger to the drying chamber and another small one coupled to the furnace to generate oxygen and facilitate combustion. The turbine of the drying chamber was built with steel sheet pallets and with an adapted aerodynamics so that the air flow is large. The furnace turbine had the identical structure, but in small dimensions.

In the prototype, the pre-cleaning step is necessary for sifting the coffee grounds (as in the commercial standard). Pre-cleaning is carried out in a rectangular container, with a perforated screen at the bottom, which performs the sieving through vibrating movements coming from an off-center shaft fixed to the structure with bearings and bearings.

In the burner, responsible for feeding the furnace of the prototype, a 24 Vdc direct current motor was used. A feature of this design is that the motor output must have reduced speed and sufficient power to provide the required torque. For this, the conversion given by the equation described below was performed:

$$P = F.V \tag{1}$$

Where **P** is power defined in Watts (W), and **F** is force in Newton (N), and **V** is velocity in meters per second (m/s).

Through Eq. (1) we have that: keeping the power constant and reducing the speed, the force will be increased to maintain equality. In practice, the speed/force conversion was carried out by a motor with a coupled reducer and complemented with reduction gears.

The option for the direct current motor is due to the ease of control through voltage variation, in addition to its reduced size. This enables the implementation of speed control, and consequently fuel flow control.

4. RESULTS AND DISCUSSIONS

To test the functioning of the prototype, around 20 liters of sample coffee were placed so that the entire screen of the drying chamber was covered to prevent air from escaping. In dryers on a commercial scale, around 1000 kilos of coffee are required at least.

To read the temperature curve of the coffee dryer, serial communication was used between Microgênios PIC KIT and LabVIEW®. The software used was Microgênios' MikroC, which has the advantage of having a vast library. The microcontroller chosen was the PIC 18f452, which, in addition to being low cost, has several characteristics compatible with the needs of future projects, such as a sufficient number of analog ports and a good memory capacity.

The sensor used in this project was the TMP36. The choice was due to the fact that this sensor is already calibrated at the factory and has an upper measurement limit of 150°C. This measurement range matches what is desired for the temperature measurement of this project. This sensor has a good degree of accuracy, but accuracy can be compromised in the presence of noise, with increased variation. To transmit the measurement values, a microphone cable was used, which in turn is shielded, so that noise problems are mitigated.

The challenge of building the coffee dryer prototype was to reduce it as much as possible without losing the performance of functions, and maintaining the desired operation. It was built in 1:5 scale in relation to commercial size machine. In this case, considering the dimension in volume, the dryer prototype was reduced around 125 times. Due to its reduced size, it could be difficult for the coffee to circulate through the dryer. Since, the size of a coffee bean with husk remains the same logically, and performing the comparison with the downsizing of the dryer, the proportion of the coffee bean would be 125 times greater in volume in the prototype than in a commercial dryer. However, the prototype performed excellently and was able to make the coffee rotate normally and perform all the tasks that the commercial size dryer performs. The choice of scale was right, as it was proven that the drier on a reduced scale is capable of working just like the drier on a commercial scale. In addition to the ease of use, as it can be transported with ease. Therefore, it is a suitable application for the laboratory.

Some innovations were made in the mechanics of the prototype that enabled an improvement in the functioning of the machine. Like the hexagonal-shaped silo construction, and consequently, it presented better coffee circulation compared to commercial dryers that have cylindrical rings. Since the dryer with hexagonal silo no longer stops grain in the corner of the first ring, like the cylindrical dryers. The built prototype can be seen in Figure 4.1.

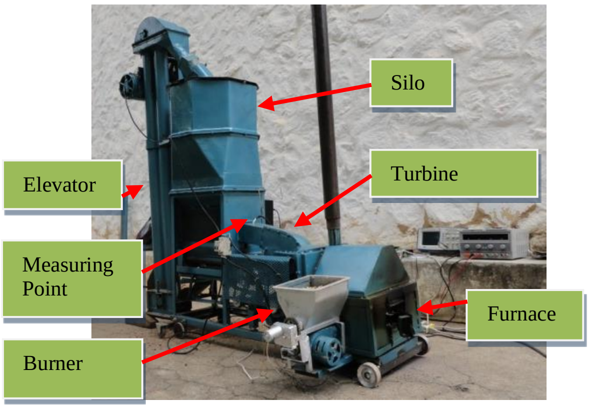

Figure 4.1 – Photo of the coffee dryer prototype in operation (Source: From the author, 2013)

As can be seen the prototype can be moved easily. Because all parts of the dryer are installed on a rail with wheels. This facilitated the displacement of the prototype in the mechanical laboratory of CEFET MG, as it is heavy, especially with the load of coffee.

The bucket elevator had an excellent operation, being able to transport coffee with the desired speed and flow. The pre-cleaner with its vibrating movement was able to sift and move the coffee. The turbine had a good ability to move hot air, contributing to the good functioning of its thermodynamics. The drying chamber together with the turbine can be proven to work, because in the first test, which lasted about two hours, it was possible to observe that the coffee was dry.

In the case of the feeder, the conversion of speed into force in the part of the electromechanical reduction system, presented the desired result. The speed was propitious to be controlled, as there was an increase in force, in order to prevent disturbances from impairing the flow control. Figure 4.2 illustrates the feeder (burner) and the furnace.

In this figure, the burner feeding the furnace can be seen, and the oxygenation turbine can also be seen, just like the flame in the wood sawdust, thus proving the good combustion capacity of the furnace, an important fact, considering the little space for the flame. The furnace as a whole showed excellent performance.

It can therefore be concluded that it was well dimensioned, especially the heat exchanger, which is an important part of the system. It was also possible, through real graphs, to prove the correct operation of the thermodynamic system of the dryer, as can be seen in figure 4.3:

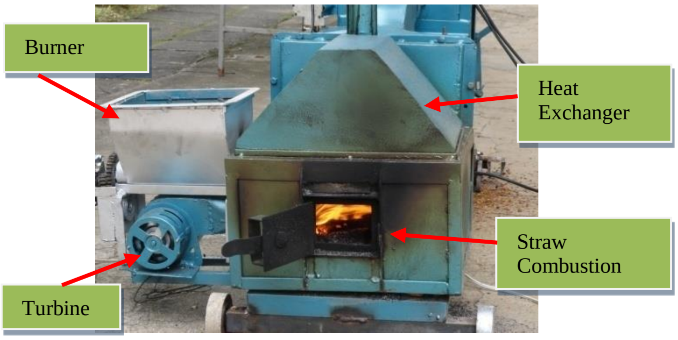

Figure 4.2 – Furnace feed (Source: From the author, 2013)

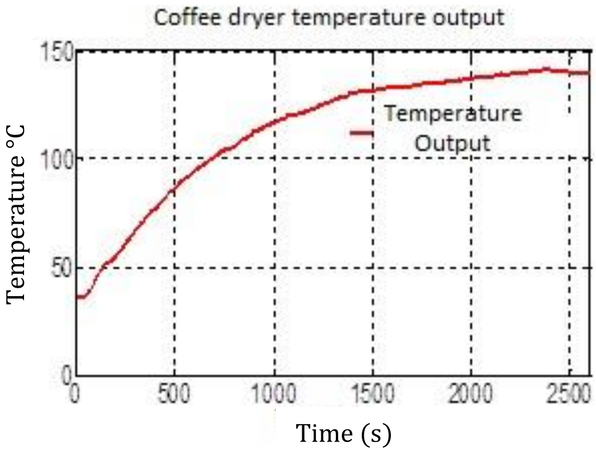

Figure 4.3 – Prototype temperature curve (data collection in January 2013) (Source: From the author, 2013)

This graph contains the temperature values as a function of elapsed time. The temperature measurement was performed on the CEFET MG campus in the city of Leopoldina MG. The initial temperature value was 36°C and the maximum value of the measured curve was 140°C. Since the commercial dryer works at a maximum of 120°C in coffee with low humidity, then the performance of the heating system is good in this question.

Obtaining the temperature curve lasted up to 1500 seconds, as in this time the system had already reached its maximum value. From this moment on, the temperature values tended to become constant (steady state).

The maximum temperature value was conditioned to the maximum power of the burner with the speed reduction used, if you remove some of the reduction and increase the burner speed, the temperature output can be higher, until the maximum combustion capacity of the furnace is reached. However, if the speed is increased beyond the furnace's combustion capacity, it may clog the furnace with excess fuel, that is, the system has reached a point of instability.

Despite the use of a microphone cable (which in turn is shielded) for transmission of measurement values, the temperature curve showed noise. To solve this problem, a LabVIEW® code was implemented to filter the noise of the reaction curve signal. Therefore, in future control projects, if the process transfer function contains noise, it may make the control project unfeasible by identification methods.

One of the advantages of building the prototype was the possibility that it could be transported, otherwise it would be difficult to carry out tests in laboratories, because a plant on a commercial scale would have to be used, which can make academic projects unfeasible. Even if it is possible to test it in the field, it is time consuming and costly, as they are large machines and require a large amount of energy, fuel and sample coffee for drying tests.

The tests must be carried out outside the coffee harvest, due to the occupation of the dryers. Large quantities of sample coffee should be reserved, as in off-season it is difficult to find coffee available for drying. The use of a dryer on a commercial scale can become unfeasible, as it would have to put the machine in operation for several days to carry out the projects, which can be mechanical, thermodynamic, aerodynamic, automation and system control. Thus, the great contribution of this work was to design and build a prototype of a coffee dryer on a reduced scale with the objective of making research on the product (coffee), the drying process and the equipment feasible.

The dryers available on the market have a capacity of 15000 liters to 20000 liters, sometimes being unnecessary or inaccessible to the small producer, as the price is high. Thus, another contribution would be a dryer on a reduced scale, of around 5000 liters, which may be an option for small producers who do not have the need to purchase a dryer on a commercial scale, due to their small production.

5. CONCLUSIONS

The project presented better thermodynamic and mechanical functioning than was initially expected. There are several factors that involve the success of a project, but one of the main requirements is low cost. This objective was obtained in this project, because with few resources a system was achieved that contributes to the creation of innovative projects for the mechanical drying of grains.

With the construction of the prototype of the dryer, it is possible to carry out tests on equipment that works as it does or even better than what is found in the field. Future projects to optimize drying processes using this prototype can be expanded to several other types of grains, such as corn and soybeans.

The main objective of this work was achieved, the possibility of using this mini plant to carry out projects in college laboratories. Projects that aim to optimize the coffee drying process, meeting the demand of the national and international market, which are increasingly demanding in terms of product quality and are also concerned with the efficiency of the process, since sustainability has become a requirement of those who consume quality products.

A tool was built to aid research with dryers, aiming at the use of modern technologies, which helps the producer in the search for market demands and consequently provides an increase in the profit margin.

The next jobs with the mini dryer could be: measurement of other variables involved in the process for sizing the dryer; automation of the drying process and subsequently control the thermodynamic system. Projects can also be carried out using the concept of internet of things, among many other scientific projects.

In this case, this work tends to be an innovation that creates incentives for the agrarian sector, which in turn sustains the Brazilian economy in various moments or economic contexts.

6. ACKNOWLEDGEMENTS

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