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Identification of energetically critical processes for cocoa production in Santander, Colombia

Camilo Leonardo Sandoval-Rodriguez[1], Carlos A. Angulo[1], Arly Dario Rincón-Quintero[2], Javier Ascanio-Villabona[1], Omar Lengerke[3]
[1] GISEAC – Research Group on energy systems, automation and control, Unidades Tecnológicas de Santander
[2] DIMAT – Design and Materials Research Group, Unidades Tecnológicas de Santander
[3]GICAV – Advance Control research group, Unidades Tecnológicas de Santander

ABSTRACT

The intensification of industrial activities in post-harvest cocoa processes has generated a disproportionate increase in energy consumption. The objective of this work is to describe those energetically critical ones that are used in the cocoa production line in Santander so that further research can evaluate the implementation of alternative or renewable energy systems. Through the collection of information and data management, it is seeking to promote the efficient use of energy based on the NTC ISO 500001. For this end, a description of the processes involved in the production of cocoa was made considering the technical data. Then, the energy consumed by the equipment used in the different processes was determined for 30 days, operating 24 hours a day, assuming power factors of 0.75 and 0.9. Finally, through analysis, calculations, and the application of the Pareto methodology, it was possible to identify that the process with the highest energy consumption is the cocoa refining step, since the equipment used in this process consumes more than 30% of energy from the total energy used for cocoa production.

Keywords: Cocoa production, Critical processes, Energy consumption

Corresponding Author:

Camilo Leonardo Sandoval Rodríguez
Faculty of Natural Sciences and Engineering, Unidades Tecnológicas de Santander/GISEAC-Research Group, Colombia
Address: Calle de los Estudiantes #9-82 Ciudadela Real de Minas-Bucaramanga-Santander-Colombia
E-mail: csandoval@correo.uts.edu.co

1. Introduction

In Latin America, Colombia is the fourth cocoa producing country after Brazil, Ecuador and the Dominican Republic [1], [2]. Colombia is a country that has great geoclimatic conditions that allow the development of the agricultural sector. This is how it stands out for its biodiversity and great variety of microclimates that generate great potential for the cultivation of different species [3]. In 2020, more than 29,000 tons of cocoa were harvested on around 54,000 hectares in Santander, making it the region with the highest production in Colombia [4], [5]. However, in recent years the agricultural sector has been presenting production, economic and sales problems that lead to the income of small growers not even being able to cover production costs [6].

To obtain cocoa products after harvest, the cocoa sector uses different types of agricultural machinery and purely manual techniques [7]. The equipment used in the cocoa post-harvest processes requires energy for its operation. The power consumption of this equipment varies depending on its capacity and efficiency, however, there is no complete identification of the energy-critical processes in cocoa production [8]. Knowing the distribution of this consumption becomes a starting point to establish action plans that help mitigate the environmental impacts in the various industrial processes and to comply with regulatory standards [9], [10].

The present work seeks to identify the processes that are energetically critical in the cocoa production line. For this, a documentary base of all the cocoa production processes is built, the industrial processes are classified separating them from the natural processes, the description of the industrial processes is made from their operating principles and technical characteristics, and finally the consumption of each equipment are determined.

2. Equipment associated with cocoa production

Cocoa beans must undergo post-harvest processing on farms and plantations comprising the steps of pod opening and beans removal from the pod, beans fermentation and drying before they can be traded and processed into final industrial products [11], [12], [13]. Figure 1 shows all the processes of the cocoa production chain. It should be noted that, in addition to the products obtained through the processes shown in Figure 1, some of their residues, such as the ash from the shell of the cocoa pod, can be mixed with other recyclable materials to be used in the parts manufacturing [14], [15], [16].

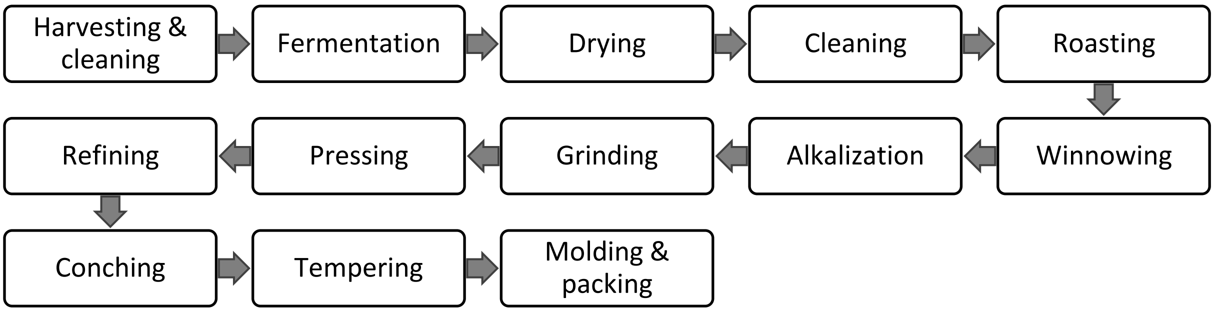

Figure 1. Cocoa production chain processes

The processes involved in the production chain and the equipment used in each of them are listed below.

- **Harvesting & cleaning:** It consists of opening and removing the seed with its slime from the cob. This must be done with the ripening of the fruits, which is recognized by their color and occurs every 165-180 days after the fertilization of the flower. It is suggested to harvest weekly to avoid plant diseases. This process uses industrial scissors that do not consumes any energy.
- **Fermentation:** It is a process of great importance since it is directly related to the quality of the grains. The best possible chocolate flavor will be developed in the seed by having a biochemical change in the bean. It takes about 3 to 6 days with the removal process at temperatures of 40 to 45 ° C to achieve changes in color, taste, and smell. There is no electricity consumption in this process either.
- **Drying:** This process aims to reduce the moisture with which the grain ends once the fermentation stage is over. It is sought that the humidity that the grains have is less than 7% to guarantee the quality of the grain, avoiding the appearance of fungi in its commercialization. For this, cocoa dryers are used to distribute heat between the cocoa beans, exchanging the heat vertically first to the top and then to the bottom, obtaining uniform drying [17]. Table 1 shows different equipment used in this process and its power.

Table 1. Electric power of the equipment used in the drying process.

	Model	Power [kW]	Productivity [kg/h]
A:	G20	1.93	500
B:	AS-15	3.728	1150
C:	SGV	5.21	1000
D:	SLH 2-6	5.59	300

- **Cleaning:** Here, any material or object other than the cocoa bean (metals, stones, pieces of wood, among others) is segregated to guarantee that only the raw material enters the production process. Table 2 show the electric power of industrial cocoa cleaners that have vibrators and sieves are used to remove those objects unrelated to cocoa production.

Table 2. Electric power of cocoa cleaners.

	Model	Power [kW]	Productivity [kg/h]
A:	B. CLEANER	0.45	200
B:	CPFBNR 1X	4.10	2000
C:	NA-1	3.72	1000
D:	NA-3	5.21	3000

- **Roasting:** It consists of heating the cocoa for a few minutes, producing chemical changes of free amino acids, and reducing sugars, thereby obtaining the best aroma and characteristic flavor of chocolate. Additionally, it seeks to darken the color, facilitate the detachment of the shell, and eliminate any type of microorganism [18], [19]. Table 3 show the electric power of industrial polyfunctional toasters that are used in this process. These machines, which can also be used to roast peanuts, cereals, and grains of various products, have temperature control and a compartment that allows the extraction of product samples.

Table 3. Electric power of polyfunctional industrial toasters.

	Model	Power [kW]	Productivity [kg/h]
A:	FISCHER	0.37	500
B:	TD-50	1.11	200
C:	ROASTY 70	2.2	70
D:	TCV-30	2.23	30

- **Winnowing:** The process consists of separating the skin and the grain after its roasting process and without causing any type of damage to the grain through the difference in density. The machines used for this purpose have shellers based on geared motors and fans that remove the cocoa shell without mistreating it. Table 4 shows the electric power of these machines.

Table 4. Electric power of the equipment used in the winnowing process.

	Model	Power [kW]	Productivity [kg/h]
A	WINDCRACKER	5.25	200
B	DESC-100	2.05	100
C	DCV-30	2.93	600
D	PEL-4	4.10	200

- **Alkalization:** In this process, also known as "dutching", the color of the cocoa is modified, its flavor is intensified and its natural solubility is increased [20]. For this purpose, industrial mixers are used to mix the cocoa with a solution of a specific alkaline compound to obtain a homogeneous mixture without any type of lumps. Common alkaline compounds are calcium carbonate, potassium carbonate and sodium hydroxide. The resulting product color ranges from light red to charcoal black.

Table 5. Electric power of mixers used in alkalization process.

	Model	Power [kW]	Productivity
A	MHV-500	5.59	500 kg/h
B	MHV-100	11.18	1000 kg/h
C	CHOCOMIX300	4	300 L
D	CHOCOMIX500	7.5	500 L

- **Grinding:** The cocoa is brought under compressive and frictional forces to transform the bean into cocoa mass, liquor or paste. Pin and blade mills are the machines used to grind dry cocoa beans and other derivatives in a homogeneous manner, preventing the grain from sticking to the equipment.

Table 6. Electric power of mills.

	Model	Power [kW]	Productivity [kg/h]
A	MUV60-60	29.82	400
B	PICAMOL300	5.59	250
C	INOX 3	7.45	350
D	MTC 250	3.72	250

- **Pressing:** Cocoa paste is subjected to extreme pressure in order to separate the solid part (i.e., the cocoa) and the liquid part (i.e., the cocoa butter) [21]. The machine responsible for exerting high pressure on the cocoa beans is the industrial press. This machine has a cylinder that works for hot or cold pressing and a piston to exert pressure on the content.

Table 7. Electric power of industrial press.

	Model	Power [kW]	Productivity [kg/h]
A	6YY-260	2.2	600
B	AMEO-100T	2	30
C	6YZ-400	3	25
D	DTC-CAPR 200	4	200

- **Refining:** The aim is to reduce the granulometry of the solid particles to about 25 microns, thus generating a finer paste. The machine used to refine the cocoa paste has steel rollers that generate high pressures [22]. Table 8 shows the electric power of these equipment.

Table 8. Electric power of refining machines.

	Model	Power [kW]	Productivity
A	MONTY 3000	55	3000 L
B	MONTY 2000	37	2000 L
C	MOLROD500	3.72	300 kg/h
D	MUV 60-60	29.82	400 kg/h

- **Conching:** In this phase, the caramelization reaction occurs, the volatile acids are eliminated and the moisture present in the refined paste evaporates to extract those unwanted flavors in the product and thus obtain a suitable emulsion. The refined paste is subjected to a temperature of 80°C while it is shaken and kneaded through agitators to obtain a better paste flavor and with the necessary properties [23]. Table 9 shows the electric power of the mixers with blades used in this stage**.**

Table 9. Electric power of mixers used in the conching stage.

	Model	Power [kW]	Productivity [L]
A	ROCKY 40	1.5	40
B	CHOCOMILL1000	11	1000
C	CRV-20-I	2.23	30
D	MONTY 500	15	500

- **Tempering:** This process is carried out in order to ensure the resistance of the chocolate to any type of heat. It consists of reducing the temperature to which the product was subjected and causes the fat present in the cocoa powder to crystallize in the correct form [24]. The machine that performs the functions of tempering, molding, and vibrating the chocolate works through a heat induction system and an automatic gas cooling system, which reduces cooling time.

Table 10. Electric power of the equipment used for tempering

	Model	Power [kW]	Productivity [kg/h]
A	THERMINATOR-3	2.5	120
B	CHOCOTEMP100	4.75	100
C	CHOCOTEMP200	7.5	250
D	CHOCOTEMPER24	3	24

- **Molding & packing:** The chocolate is poured into molds that are sent to a cooling tunnel at low temperatures to give it the texture with which the product will be marketed. Finally, the product is taken by a conveyor belt to packaging machines that give its final presentation. The cooling tunnel is made up of a conveyor belt inside a thermally insulated closed compartment into which cold air is injected.

Table 11. Electric power of the cooling tunnel.

	Model	Power [kW]
A	FRIGOBELT100	2.23
B	LST	14
C	YC-T-C800	36
D	SJP-400	16

Table 12. Electric power of the packing system.

	Model	Power [kW]
A	BOMBOMPACK	0.746
B	PACKER300	1.6
C	CHOCOPOT5000	1.3
D	CHOCOPOWDER2000	4

3. Results

Considering the information consigned from Table 1 to Table 12, the average energy consumption was estimated for all the equipment involved in each of the processes of the cocoa production line, taking into account a 720-hour operation (24 hours a day for 30 days). Figure 2 shows a summary of the real power of each piece of equipment while Figure 3 shows the average energy consumption per process. As can be seen, the Model D equipment used in the refining process (i.e., the MUV 60-60) turns out to be the one that consumes the most energy in the cocoa production chain.

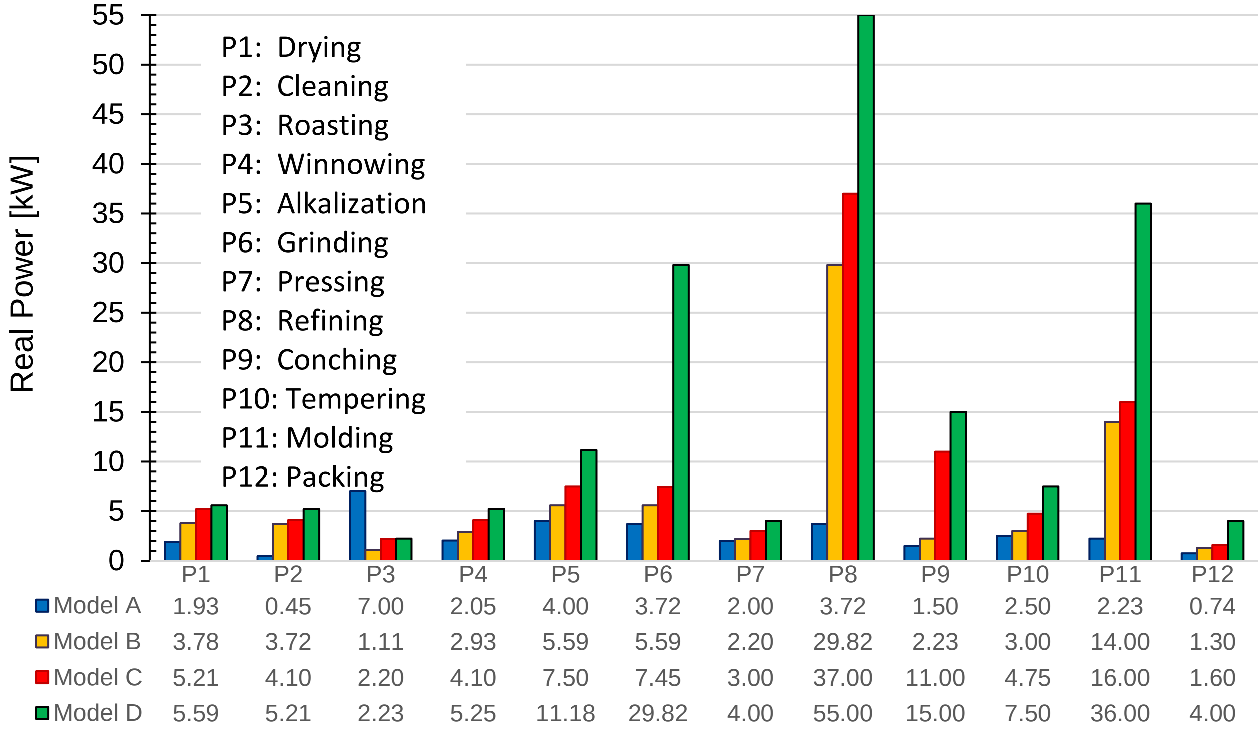

Figure 2. Energy consumption of the equipment used in the cocoa production chain. “P1”, “P2”, etc. correspond to the processes in the production chain while “Model A”, “Model B”, and so on are the models of the equipment used in the respective process

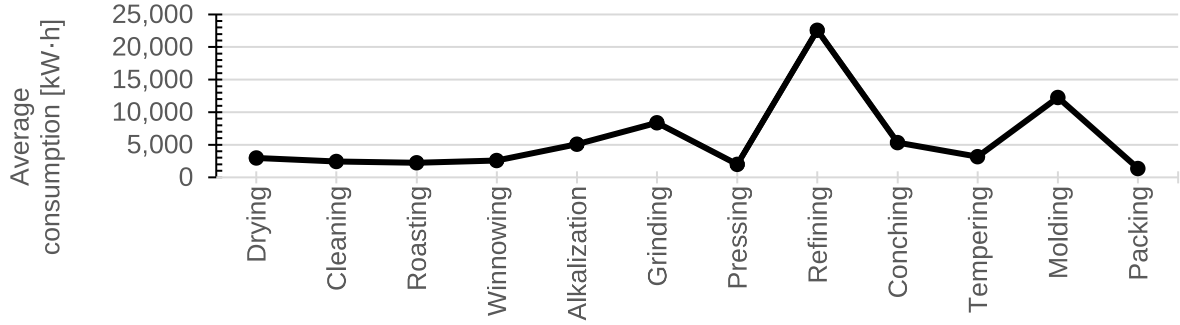

Figure 3. Average energy consumption per process in 720 hours

Table 13 and Table 14 show the estimated average apparent power and reactive power for power factors of 0.95 and 0.75, respectively.

Table 13. Average Apparent power and Reactive power per process for power factors of 0.95

PROCESS	Average Apparent Power [kVA]	Average Reactive Power [k var]
Drying	4.34	1.36
Cleaning	3.55	1.11
Roasting	3.3	1.03
Winnowing	3.77	1.18
Alkalization	7.44	2.32
Grinding	12.26	3.83
Pressing	2.95	0.92
Refining	33.04	10.32
Conching	7.82	2.44
Tempering	4.67	1.46

Molding	17.96	5.61
Packing	2.01	0.63

Table 14. Average Apparent power and Reactive power per process for power factors of 0.75

PROCESS	Average Apparent Power [kVA]	Average Reactive Power [k var]
Drying	5.50	3.64
Cleaning	4.49	2.97
Roasting	4.18	2.76
Winnowing	4.78	3.16
Alkalization	9.42	6.23
Grinding	15.53	10.27
Pressing	3.73	2.47
Refining	41.85	27.68
Conching	9.91	6.55
Tempering	5.92	3.91
Molding	22.74	15.04
Packing	2.55	1.68

Figure 4 and Figure 5 show the Pareto diagram for the consumption of apparent energy and reactive energy, respectively. The consumptions were determined for a power factor of 0.95, taking into account 720 hours of operation. As can be seen, the refining and molding processes turn out to be energy-critical since the equipment used in these two stages consumes around 50% of the total energy consumed in the entire cocoa production chain.

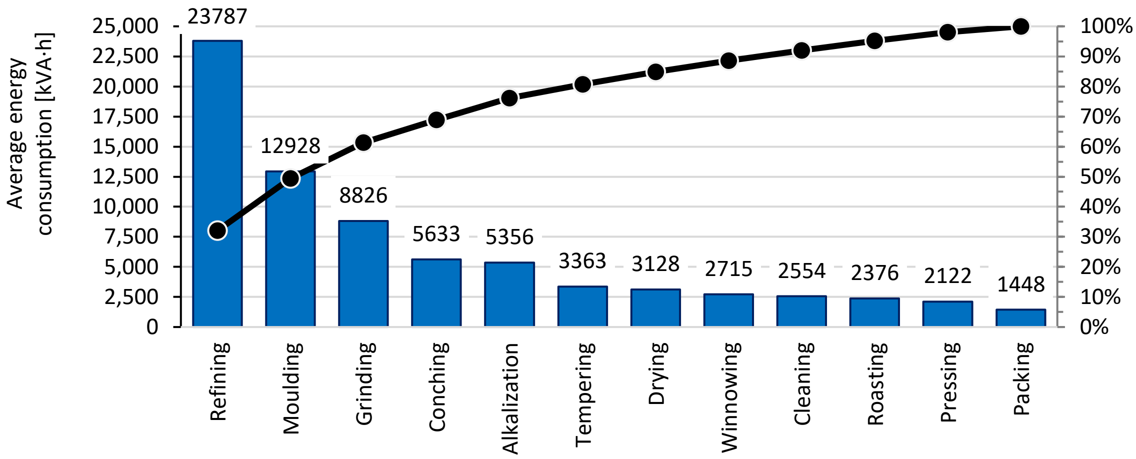

Figure 4. Pareto chart for the estimated average apparent power consumption for a power factor of 0.95

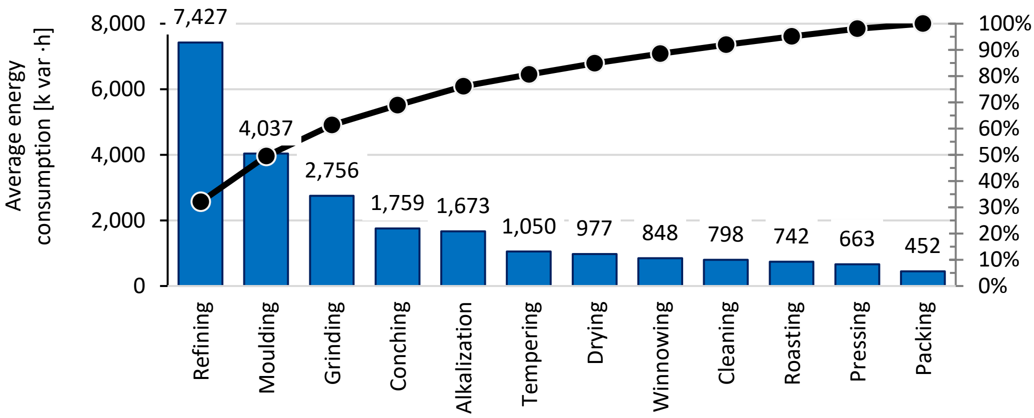

Figure 5. Pareto chart for the estimated average reactive power consumption for a power factor of 0.95

4. Conclusions

Through this study it was possible to collect information on the processes in the production of cocoa, from obtaining its raw material to the final product. The description of the processes was based on the classification of technical characteristics of the equipment and functional characteristics. The Pareto charts allowed us to identify that the area with the highest energy consumption is the cocoa refining process followed by the cocoa molding and grinding processes.

With this information, various strategies can be proposed that involve alternative energies in order to contribute to energy performance and to reduce costs in the cocoa production chain. The latter taking into account the investment rate, the rate of return on investment in a given time and the savings generated.

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