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Improvement of the lactose grinding process for a company manufacturing dairy products

Mejora del proceso de molienda de lactosa para una empresa fabricante de productos lácteos

Darío J. Pinguil Loja[1], Víctor R. Lojano Pillco[1],
Nelson G. Jara Cobos[1,*], Fran Z. Reinoso Avecillas[1]

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Abstract

This research presents results obtained after the implementation of an improvement in the lactose grinding process of a company which manufactures dairy products. The current situation of the process was determined identifying that a lactose particle size of 40.23 µm is obtained in a grinding time of 48 continuous hours. After theoretical and experimental research processes, it was obtained as the best option a fine grinding with an average particle size of 22 µm in a grinding time of 5 continuous hours, using a drum mill with a volume of grinding elements of 25% and an operating velocity of 61 rpm, and the Cylpebs as specified in this research work; this generates savings in raw material (lactose), energy consumption and operation time of the grinding process.

Keywords: Lactose, particle size, granulometric analysis, cylpebs distribution

Resumen

Esta investigación presenta resultados obtenidos luego de haber implementado una mejora en el proceso de molienda de lactosa de una empresa fabricante de productos lácteos. Se determinó la situación actual del proceso, identificando que, en un tiempo de molido de 48 horas continuas, se obtiene un tamaño de partícula de lactosa de 40,23 µm. Posterior a los procesos de investigación teórica y experimental se estableció que con el uso de un molino de tambor con un volumen de elementos molientes del 25 %, una velocidad de operación de 61 rpm y el uso de cylpebs especificados en este trabajo, representan la mejor opción para obtener una molienda fina con un tamaño promedio de partículas de 22 µm en un tiempo de molido de 5 horas continuas, lo que genera principalmente un ahorro por materia prima (lactosa), consumo energético y tiempo de operación del proceso de molido.

Palabras clave: lactosa, tamaño de partícula, análisis granulométrico, distribución de cylpebs

[1,*]Grupo de Investigación y Desarrollo en Simulación, Optimización y Toma de Decisiones GID - STD, Universidad Politécnica Salesiana, Ecuador. Corresponding author ✉: njara@ups.edu.ec .

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1. Introduction

The quality policies and the global market in general demand industries that they produce better quality products, i.e., the market becomes more competitive, making the task more difficult for many industries that want to remain in the market and, especially, open new niches.

This project develops a proposal for improving the lactose grinding process, used as raw material for producing condensed milk; in this sense, it has been sought to purely achieve the reduction of the particle size, with the purpose of obtaining a better consistency in the final product.

At the initial stage, it is determined the results of the current situation of the grinding process parameters such as, operating time, grinding velocity, volume of raw material (lactose) and particle size. The aim of this is to set the goals necessary to fulfill the attainment of an average size of the particle of 25µm, feature required to manufacture condensed milk in the company. Afterwards, an experimental analysis was carried out to determine the best type of mill that enables to reduce the size of the particles and the grinding time.

The improved particle size is determined by means of the macroscopic measuring process.

The results obtained prove that the size of the lactose particle as raw material significantly improves the quality of the condensed milk texture, as one of the dairy products that employs this raw material.

The work of analysis, proposals for improvement, experimental development and measurements is found in a comprehensive manner in the final report of the work by Lojano Pillco *et al.* [1].

1.1. Parameters that influence the grinding process

There is a series of parameters that influence the lactose grinding process [2], some of which are presented below:

- Critical velocity
- Mill operating velocity
- Relationship between the variable elements of the mills
- Size of the grinding elements
- Load volume
- Distribution of the material to be grinded
- Power
- Mill types

1.1.1. The critical velocity

Is the one that occurs when the centrifugal force cancels the influence of gravity on the balls. The following equation (1) determines this critical velocity [3].

$$V_c = \frac{42,3}{\sqrt{D}} \quad Metric\ system \tag{1}$$

Where:

V_c = Critical velocity in rpm
D = Mill diameter [m]

1.1.2. The mill operating velocity

Should be smaller than the critical velocity; the operating range of the ball mills or cylpebs is chosen between 65% and 80% of V_c [4]. Figure 1 shows the movement of the mill with its cascade and waterfall effects, respectively.

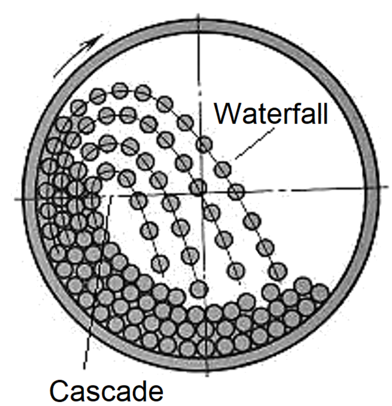

Figure 1. Movement of the load in a ball mill [5]

Equation (2) is presented for calculating the operating velocity [5].

$$V_{op} = V_c \times \%V_c \tag{2}$$

Where:

V_{op} = Operating velocity
V_c = Critical velocity in rpm
$\%V_c$ = Percentage of critical velocity

1.1.3. The relationship between the variable elements of the mills

Considers mill variables such as critical velocity, mill internal diameter and grinding bodies [2].

1.1.4. Maximum size of the grinding elements

Should not present a unique uniform size, but a distribution of the grinding elements is made from the maximum diameter, but at lower sizes. The maximum size of the grinding elements is obtained from the percentage distribution and the corresponding dimensions of the components to obtain an effective grinding.

1.1.5. The load of the grinding bodies

Makes reference to the fact that the mills do not operate totally full. The volume occupied by the grinding elements and the material to be grinded referred to the total volume of the mill cylinder is known as the load of the grinding bodies, which is calculated using equation (3) [2].

$$B = V_m \times b \times 0,6 \times \delta_b \tag{3}$$

Where:

B = Weight of the grinding bodies [kg]
b = constant (0,2 – 0,4)
V_m = Volume of the material in dm^3
δ_b = density of the cylpebs 7,8 kg/dm^3
D = nternal diameter of the mill cylinder
L = nternal length of the mill

The degree of filling in the lactose grinding using cylpebs typically comprises a load between 25 and 33% of the total volume, and is constituted by the grinding bodies and the material to be grinded [3].

1.1.6. The distribution of size of the grinding material, balls or cylpebs

It may be determined through various methods, of which two were used in this research:

Method 1. According to the diameter. Once the initial load of the grinding material is known, the diameters of the balls that are planned to be used are added. The sum corresponds to 100%. Afterwards, the percentage corresponding to the value of each diameter is determined. The result obtained corresponds to the percentage in weight of the initial load, which corresponds to each size of cylpebs.

Method 2. According to the diameter with Bond formula. Once the initial load of the grinding material and their maximum size is known, the distribution percentage corresponding to each ball size is determined using: $Y = 100(X/B)^{3/2}$; this is taken to the graph to determine the percentage in weight corresponding to each commercial size of cylpebs that should be fed.

Regarding the percentage distribution of the grinding means as a function of the diameter, it is applied Bond formula given by equation (4) [6].

$$y = 100 \left(\frac{x}{B}\right)^m \tag{4}$$

Where:

y = % weight of grinding means with diameter below x
B = aximum ball diameter [in] or [mm]
x = diameter of the ball to be distributed [in] or [mm]
m = constant, its values are:
(3,2 for rod mills or cylpebs)
(3,84 for ball mills)

1.2. Lactose

The lactose appears as white crystalline particles or powder. They are traditionally used in manufacturing pills, and it is considered a sugar of great importance in the food processing industries. It is an excellent excipient of tablets and pills, among many other applications.

The solubility of lactose is ten times smaller than that of sucrose, if sugars added are summed, the immediate problem will be to avoid the saturation of the solution, since when the saturation limit is reached the excess of sugars will precipitate as crystals forming lumps, physical defect that commonly appears in commercial sweets [7]. In this sense, using a lactose with a particle size around 30 μm results very convenient to improve the quality of dairy products such as condensed milk.

1.3. Methods for measuring the particle size

The methods of granulometric analysis by sieving and microscopic visualization were used in this project.

1.3.1. Granulometric analysis by sieving

It is one of the most ancient techniques for classifying powders through sieving. It is among the most commonly used and less costly techniques for determining the particle size distribution in a wide range of sizes, from little more than 100 mm to approximately 20 0 μm [8] (Figure 2).

Figure 2. Sieve and sieving process

A complete granulometric analysis consists in passing a material, in general 100 grams representative of the original sample, through a series of sieves, starting with a lower number of meshes and ending with the one with the higher number.

Table 1 presents the sieve designation according to what is established in the ASTM E-11 standard.

Table 1. ASTM sieve designation and corresponding aperture openings [9]

ASTM Sieve Designation					
Aperture Opening	**Designation**	**Aperture Opening**	**Designation**	**Aperture Opening**	**Designation**
125 mm	5.00 in.	9.50 mm	3/8 in.	425 µm	No. 40
106 mm	4.24 in.	8.00 mm	5/16 in.	355 µm	No. 45
100 mm	4 in.	6.70 mm	0.265 in.	300 µm	No. 50
90 mm	3 ½ in.	6.30 mm	¼ in.	250 µm	No. 60
75 mm	3 in.	5.60 mm	No. 3 ½	212 µm	No. 70
63 mm	2 ½ in.	4.75 mm	No. 4	180 µm	No. 80
53 mm	2.12 in.	4.00 mm	No. 5	150 µm	No. 100
50 mm	2 in.	3.35 mm	No. 6	125 µm	No. 120
45 mm	1 ¾ in.	2.80 mm	No. 7	106 µm	No. 140
37 mm	1 ½ in.	2.36 mm	No. 8	90 µm	No. 170
31.5 mm	1 ¼ in.	2.00 mm	No. 10	75 µm	No. 200
26.5 mm	1.06 in.	1.70 mm	No. 12	63 µm	No. 230
25. mm	1 in.	1.40 mm	No. 14	53 µm	No. 270
22 mm	7/8 in.	1.18 mm	No. 16	45 µm	No. 325
19 mm	¾	1.00 mm	No. 18	38 µm	No. 400
16 mm	5/8 in.	850 µm	No. 20	32 µm	No. 450
13.2 mm	0.53 in.	710 µm	No. 25	25 µm	No. 500
12.5 mm	½ in.	600 µm	No. 30	20 µm	No. 635
11.2 mm	7/16 in.	500 µm	No. 35		

1.3.2. Microscopy analysis

It is a technique that enables quickly visualizing the size and nominal shapes of the particles in a sample, and obtain a representative micrography of the region analyzed; in addition, it enables enlarging details of the shape and surface of the particles [1] (Figure 3).

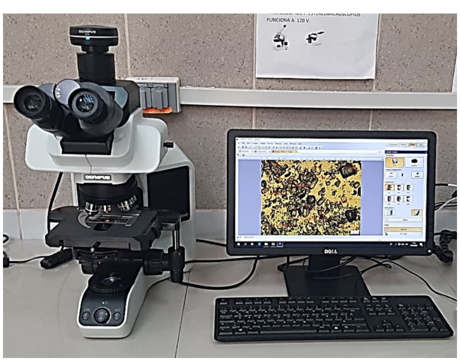

Figure 3. OLYMPUS BX43 Microscope

2. Materials and methods

For the research, it was carried out at first instance an evaluation of the current situation of the lactose grinding process carried out at the company manufacturer of dairy products, establishing the fundamental variables of the process such as velocity, distribution of the grinding material and grinding time. The samples were subject to sieves and microscopy to know the current size of the particle and, based on this information, a proposal was made for improving the lactose grinding process with the optimal operating parameters.

2.1. Description of the current lactose grinding equipment

It is used a horizontal rotating mill with a diameter of 20 cm and a length of 30 cm, capacity of 2 kg, power of 1 hp and a rotating velocity of 61.7 rpm; it employs stainless steel washers as grinding elements (see Figure 4).

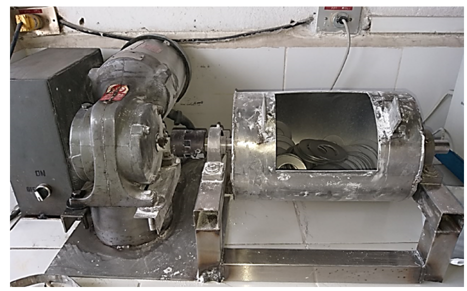

Figure 4. Horizontal rotating mill

3. Operating parameters

Table 2 presents the parameters used for the lactose grinding process.

Table 2. Operating conditions

Operating conditions	
Grinding time [h]	48
Lactose weight [kg]	2,5
Tricalcium Phosphate weight [g]	100
Velocity [rpm]	61
Grinding material	washers

Regarding the washers used for the grinding process, these are placed in a volume of approximately 12%, in a number of 40 units, whose distribution is made according to their internal and external diameter (see Table 3 and Figure 5).

Figure 5. Grinding material – Stainless steel washers

Table 3. Distribution of sizes of washers

Int. Diam. (mm)	Ext.m Diam. (mm)	Weight (kg)	Number
42	75	2,9322	37
22	50	0,1585	2
13	38	0,07925	1
TOTAL		3,17	40

As it has been mentioned, the material to be grinded is lactose, which provides sweetness to the milk. This product is commercialized in sacks of 50 kg (see Figure 6), generally with an initial granulometry of 150 μm, value determined by the manufacturer.

Figure 6. Lactose: sack and sample

With the purpose of verifying the particle size set in the raw material, it was determined the distribution of the particle size using the sieving method, considering a sample of 100 g and a stirring time of 30 min [10].

Once such procedure has been carried out [11], the previous results of the sieving process are seen in Figure 7, where the curve of % of passing accumulated represents the percentage of sample with its equivalent size, and the curve of % of retained accumulated represents the percentage of material with a larger size (x).

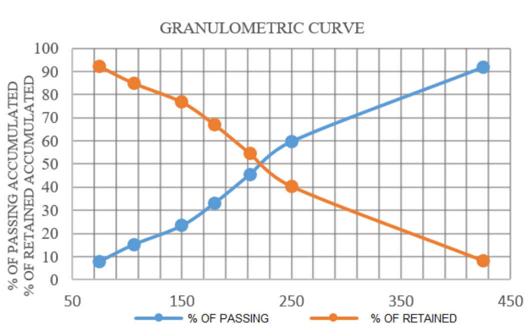

Figure 7. Percentage of passing accumulated and retained accumulated *vs.* particle size

With what has been determined and making average estimations of the particle sizes, based on the sieve distribution and relating it to the mesh size in μm and the weight of the retained fraction, values are presented to estimate the characteristic average of the distribution of lactose grain sizes as 241 μm (Table 4). This value differs from the certified size of the lactose particle size, which is 150 μm, setting the need of choosing another procedure for measuring the particle size.

The microscopic analysis enabled to quickly visualize the nominal size and shape of the particles of a sample, and obtain a representative micrography of the region analyzed; in addition, details of the shape and surface of the particles are obtained through enlargement [1].

According to the aforementioned procedure and an augmentation factor of 4x, it may be observed that the lactose particles have heterogeneous and random shapes, with different dimensions (Figure 8).

Figure 8. Lactose particles before grinding

3.1. Particle size obtained – current lactose grinding process

Once the lactose has been subject to the current grinding process, it is obtained the microphotograph of a sample, in order to determine the average size and shape of the resulting particle (see Figure 9).

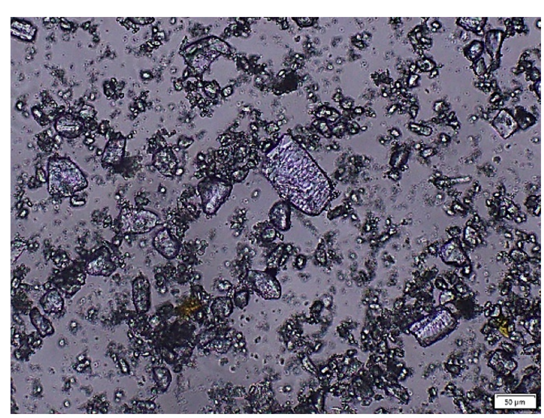

Figure 9. Lactose particles after 48 h of grinding

After 30 measurements were performed, it was obtained a minimum particle size of 19.99 μm, a maximum size of 108.67 μm, which resulted in an average of 40.23 µm and a standard deviation of 17.24 µm. In the sense, it has been possible to determine that the current process reduces the size of the particle, but, due to the heterogeneity of the particle sizes and to the larger number of grinding hours (which causes that the lactose sticks on the grinding elements), this raw material results inadequate to obtain condensed milk with the consistency required by the company.

3.2. Improvement alternatives

According to the research works, the following parameters are considered for selecting the mill type:

- Grain size to be obtained
- Grinding time
- Grinding type
- Required power
- Cost

After analyzing the weighting of the parameters applied to the four types of mills that may be employed for the lactose grinding process, namely planetary mill, attritor mill, drum mill and high energy mill, the drum mill resulted the best option, achieving the highest weighting value (see Table 4). Therefore, for the development of the present improvement project, the horizontal rotating drum mill was used, to mainly determine the optimal time, velocity and size distribution of the grinding material.

Table 4. Weighting of results – selection of the best alternative

Weighting						
Mill type	Cost	Power required	Grinding time	Grain size	Type type	Total
Planetary	3	3	5	5	1	17
Attritor	3	3	3	3	5	17
Drum	5	3	3	3	5	19
High energy	1	1	5	5	1	13

3.3. Experimental grinding tests

Three grinding parameters were taken into account for the improvement process: size distribution of the grinding material, grinding time and velocity; for this purpose, preliminary tests were carried out with different types of grinding material: balls and cylpebs.

Filling. The optimal filling of the mills is determined according to equation (5) and Figure 10 [1].

$$h = 0,16D \tag{5}$$

Where:

h = distance from the central axis of the drum
D = drum internal diameter

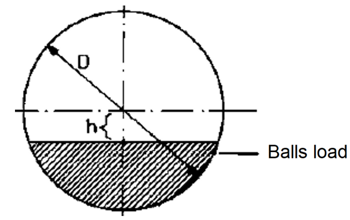

Figure 10. Filling of grinding material [1]

Critical velocity. After performing the corresponding calculations, it is determined a critical velocity of 94.5 rpm; thus, the operating velocity should be in a range from 65 to 80%, which corresponds to values between 61.425 rpm and 75.6 rpm.

Grinding material. Two types of grinding materials, balls and cylpebs, were used for the tests, with dimensional, weight and size distribution features as specified in Tables 5 and 6; for both cases it was kept constant a filling degree of 25% and a velocity of 61.4 rpm.

Table 5. Size distribution of balls

Diameters (in)	% Weight	Weight (kg)	Unit weight (kg)	Number of balls
1 ¼	55,55	3,57	0,132	27
1	44,44	2,85	0,0671	42
2 ¼	**100%**	**6,43**		**69**

Table 6. Size distribution of cylpebs

Diam. (mm)	Length (mm)	% Of weight	Weight (kg)	Unit weight (kg)	Number
1 ½	29,28	26,66	1,82	0,262	7
1 ¼	29,19	22,22	1,52	0,183	8
1	22,44	17,77	1,21	0,089	14
¾	23,01	13,33	0,91	0,051	18
05-ago	18,18	11,11	0,76	0,028	27
½	19,15	8,88	0,6	0,02	30
45/8		100%	6,85		104

4. Results and discussion

Table 7 shows the results of the five tests with different grinding times using balls as griding elements; the particle sizes were measured using the microscopy technique, in which three samples of each test performed were taken and, similarly, thirty measurements for each sample were performed, giving as result the maximum and minimum sizes of the lactose particles.

In the different tests performed, it was also observed that a larger grinding time implies larger product losses, mainly due to the agglomeration of the lactose in the mill walls and in the grinding bodies, as a result of the increment in the operating temperature [1].

Table 7. Results obtained with balls as grinding material

Losses (g)	Time (h)	Particle size (um) Maximum	Minimum
100	1	102,6	26,45
110	2	96,89	19,85
119	3	85,42	17,25
150	4	60,07	12,08
200	5	59,04	6,82

The test was performed with 1050 grams of lactose and 100 grams of tricalcium phosphate, with a minimum grinding time of one hour, because at that time the reduction in the particle size of the product begins to be noted, and a maximum grinding time established at five hours, because at that time a larger agglomeration of the product in the mill walls and in the grinding bodies begins to be noted. In this way, a good reduction in particle size was obtained according to the microscopy images (see Figures 11 and 12).

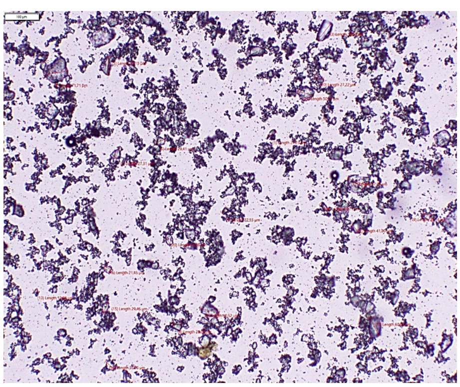

Figure 11. Lactose particles grinded for 1 h – Scale 100 µm

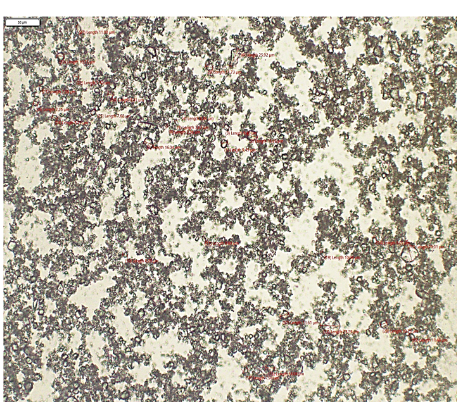

Figure 12. Lactose particles grinded for 5 h – Scale 50 µm

Table 8 presents the results of the five tests performed at different grinding times, similarly using 1050 grams of lactose and 100 grams of tricalcium phosphate; the measurement of the particle sizes is carried out using the microscopy technique, in which 30 measurements of each sample are carried out.

Table 8. Results obtained with cylpebs as grinding material

Losses	Time	Particle size (um)	
(g)	(h)	Maximum	Minimum
80	1	100,85	15,56
120	2	92,62	12,23
132	3	78,45	10,81
290	4	65,48	9,89
359	5	54,29	5,78

Figures 13 and 14 display a difference in the sizes of the lactose particles, for grinding times of one and five hours, where the sizes of the lactose particle may be appreciated.

One of the factors that are established for improving the lactose grinding process is the grinding material; in this case it is proposed to use cylpebs (stainless steel cylinders), because this shape has a larger surface area to reduce the size of the lactose particle through impact, enabling to obtain a larger number of fine particles in less time.

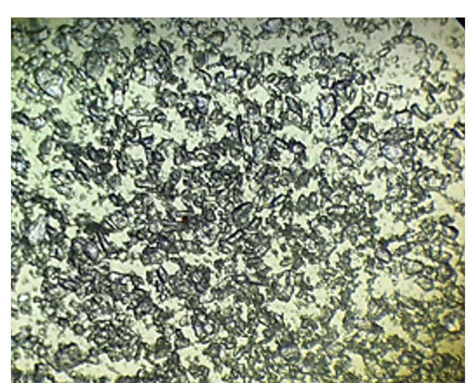

Figure 13. Lactose particles grinded for 1 h – Scale 100 µm

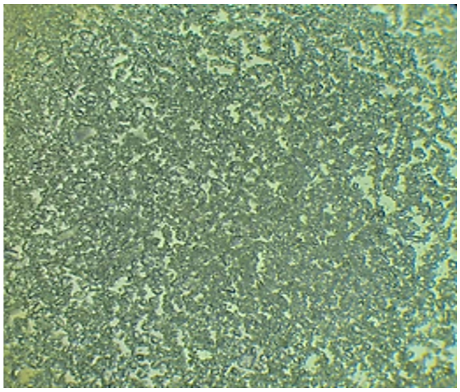

Figure 14. Lactose particles grinded for 5 h – scale 100 µm

Operating parameters such as the time, velocity and size distribution of the cylpebs, should be controlled for the grinding to be effective. These improved parameters are presented in Table 9, which are compared with the results of the current situation of the company.

Table 9. Improved operating parameters

Parameters						
% Load volume	**Velocity [rpm]**	**Grinding time [h]**	**Grinding material**	**Weight (kg)**	**Number**	**Size [um]**
12	61	48	washers	3,174	40	40,23
25	61	5	cylpebs	6,85	104	22

5. Conclusions

The variables identified that have influence on the lactose grinding process are the size distribution of the grinding material, the grinding times and the velocity, which impact the size of the lactose grain.

Through the grinding tests performed in the drum mill, it was possible to determine the adequate operating parameters for the grinding process. Consequently, the cylpebs were selected as the most efficient grinding material for the grinding process in fine products, with an effective grinding time of 5 hours.

The selection of the cylpebs as grinding elements is because they offer a larger surface area for breaking the lactose particles through impact, thus being more effective in less time with larger number of fine particles, enabling to obtain a grain size of 22.075 µm in a grinding time of 5 h.

The lactose load applied to the grinding was optimized, because with less operating hours the raw material does not stick on the internal walls of the drum nor on the grinding bodies, significantly reducing the losses.

With a particle size of 22 µm, it was possible to qualitatively determine (through touch) the improvement of the condensed milk texture, which represents for the company an improvement in the product quality.

References

[1] V. R. Lojano Pillco, D. J. Pinguil Loja, and N. G. Jara Cobos, *Propuesta de mejora para el proceso de molienda de lactosa en empresas láctea.* Universidad Politécnbica Salesiana, Ecuador. [Online]. Available: https://bit.ly/3a4IusB

[2] A. O. Venegas Tomalá, *Diseño y construcción de un molino de bolas para aplicaciones de pulvimetalurgia en los laboratorios de Ingeniería Mecánica de la Facultad de Ingeniería Civil y Mecánica de la Universidad Técnica de Ambato.* Universidad Técnica de Ambato, Ecuador. [Online]. Available: https://bit.ly/3R0Ewlm

[3] J. R. Alcántara Valladares, *Diseño práctico de un molino de bolas.* Instituto Politécnico Nacional, México, vol. 7, no. 2. [Online]. Available: https://bit.ly/3acXvIG

[4] O. A. Gutiérrez Gutiérrez, *Estudio para calibración de molinos.* Universidad de Chile, vol. 158. [Online]. Available: https://bit.ly/3bH0Ujm

[5] M. S. Altamirano Peralta and D. J. Sacoto Rivera, *Evaluación experimental del proceso de molienda de crudo de UCEM planta industrial Guapán.* Universidad del Azuay, Ecuador, vol. 1, no. 1. [Online]. Available: https://bit.ly/3xZFupi

[6] G. A. Villablanca Robles, *Estudio de prefactibilidad para la construcción y operación de una minicentral hidroeléctrica (MCH) en la subcuenca del río Palora*, vol. 22. [Online]. Available: https://bit.ly/3NxFJxx

[7] C. D. Char, *HACCP, Microbiología predictiva y factores en combinación para mejorar la calidad de productos lácteos: dulce de leche: aplicación del concepto de factores en combinación y de la microbiología predictiva en el mejoramiento de la calidad del dulce de leche.* Universidad de Buenos Aires, Argentina. [Online]. Available: https://bit.ly/3yy46qz

[8] R. C. Rowe, P. Sheskey, and M. Quinn, *Handbook of pharmaceutical excipients, Six Edition.* Pharmaceutical Press. [Online]. Available: https://bit.ly/3xZGlGw

[9] A. Jillavenkatesa, L.-S. H. Lum, and S. Dapkunas, "Nist recommended practice guide: Particle size characterization." [Online]. Available: https://doi.org/10.6028/NBS.SP.960-1

[10] E. J. Montes Montes and R. Torres Gallo, "Determinación de los factores de forma de área (α) y volumen (β), de cristales de α-lactosa utilizando microscopia óptica," vol. 13, no. 2, pp. 17–24. [Online]. Available: https://doi.org/10.21897/rta.v13i2.666

[11] E. A. Luna Méndez and F. T. Valencia Guaricela, *Elaboración de guías prácticas de procesos metalúrgicos para el laboratorio de minas de la Universidad del Azuay*. Universidad del Azuay, Ecuador. [Online]. Available: https://bit.ly/3Ai7fw8