DESIGN OF AN INDUSTRIAL PROCESS FOR THE PRODUCTION OF TOILET PAPER FOR THE GADIC CAÑAR

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Abstract

The objective of this work dealt to designing an industrial process for produce toilet paper from cardboard and recycled paper. Initially, laboratory experiments were conducted using different methods of deinking, defibering, and pulp bleaching; by performing quality control on the products through the application of the NTE INEN 1430 standard, the optimal and most efficient procedure was identified with a yield of 56.282%. An industrial level projection was elaborated with an economic viability analysis based on mass and energy balances. The statistical analysis for the data obtained during the quality control was carried out by implementing ANOVA and TUKEY tests, where the industrial process was demonstrated to be viable with a ARV of 5211.62, IRR of 20%, and a recovery period of approximately 4 years. However, additional bleaching methods and pulp recovery systems should be analyzed to optimize the process.

Key words: *PROCESS DESING, DEINKING, PULP BLEACHING, FIBERING, EQUIPMENT SIZING.*

1. INTRODUCTION

Toilet paper is one of the most widely used consumer products worldwide, and its demand continues to grow. However, the production of traditional paper from wood pulp is an activity that can be very expensive and impactful on the environment. For this reason, in recent years there has been a growing interest in the production of toilet paper from recycled materials, especially cardboard and paper.

The research focuses on the selection of suitable materials, the evaluation of the recycling processes necessary to obtain the raw material, the adaptation of the machinery and the design of the production processes necessary to guarantee the quality of the final product.

Obtaining toilet paper at the laboratory level is divided into two phases:

- The first phase, obtaining cellulosic pulp, encompassing the operations of defibration, purification, detinting, bleaching and chemical aggregates.
- The second phase is fixed in the formation of the sheet, here it is conditioned to the cellulosic pulp by means of only physical processes. It encompasses the processes of sheet formation, pressing, and drying.

Lopez and Vera (2008) They indicate that variations in variables such as the amount of oxidizing and reducing agent, deinking time and pressing pressure directly affect the final characteristics of the product, so an optimal balance must be achieved between all of them.

The importance of chemical aggregates in the manufacture of paper is their influence on the characteristics of this, (Braz 2007)these are used as filler or improvement additives; as mentioned, one of the Velasquez et al. (2010) improvement additives is starch since it acts on the characteristics of rigidity, strength, weight, grammage, etc., in a paper reinforcing the interfiber bonds of the cellulose pulp.

2. MATERIALS AND METHODS

2.1. Materials

The raw material used was recycled paper and cardboard. $_{H2O2}$ and NaClO were also used as bleaching agents. Starch, talc, CaCO 3 and $NaHCO_3$ served as filler material for the resulting paper.

2.2. Design of the experiment

The experimentation was performed in three different procedures, with 5 repetitions each. Each procedure had different operating conditions in the processes involved in the first phase, obtaining the pulp.

2.3. Obtaining cellulosic pulp

Defibrating: A blender was used as a shredder to obtain a homogeneous paste. Procedure 1 had no prior treatment, while procedure 2 and 3 had a detinting process.

Purification: The solid contaminants present in the pulp were eliminated, through the use of a sieve, for this, the consistency of the pulp was decreased to facilitate traffic through the mesh.

De-inking: In procedure 1, a flotation process was carried out for a time of 35 minutes, at a temperature of 40 ° C, and using a 0.15% foaming agent, which in turn, served as a detergent. For procedure 2 and 3, a soaking operation was performed, both for a time of 30 minutes; use of detergent of 0.2% and 0.15%; however, procedure 3 was performed at a temperature of 40°C while procedure two was performed at room temperature. It should be noted that the operating conditions in this process are based on those exposed by Machado and Raise (2012) for deinking by neutral method (procedure 1), and alkaline (procedure 2 and 3) at a pH of 8-9 respectively.

Bleaching: Two bleaching processes were carried out, one with sodium hypochlorite (NaClO) and the other with hydrogen peroxide ($_{H2O2}$). The pH conditions for this operation were between 9 -10. In the first stage for procedure 1, bleaching was performed with 5ml of H 2 O 2, a temperature of 50 ° C for 45 minutes; while for procedure 2 and 3 it was performed with 8 and 7 ml of NaClO respectively, a temperature of 30 ° C in both cases and for 40 and 45 minutes.

In the second stage, procedure 1 was performed with 4 ml of NaClO, while procedure 2 and 3 was performed with 1 ml$_{of}$H2O$_{2,}$ these under the same conditions mentioned above for each bleaching agent.

Chemical aggregates:

Chemical aggregates were added as a percentage, according to the following table:

Variable	Proc. 1	Proc. 2	Proc. 3	Unit
Starch	0.5	1.5	1.5	%
Talc	3	2	2	%
$CaCO_3$	2	0.5	2	%
Total	5.5	4	5.5	%

Tabla 1: *Composition of chemical aggregates for paste*

2.2.1. Leaf formation

For the formation of the leaf it was sought to decrease the consistency of the mixture to facilitate the formation of the fiber sheet, the greatest amount of water was removed by using a presser, and then the remaining water was removed by using an iron and a dryer this in order to maintain the characteristics of the toilet paper, same that are not obtained when using other types of dryers such as the stove. Finally it was cut by the rules established in the NTE INEN 1430.

2.4. Determination of quality parameters

The quality parameters were determined based on what was established by the NTE INEN 1430 for the grammage, resistance to rupture by longitudinal traction, absorption time and dimensions. In addition to this, other parameters were measured, such as pH and humidity, for which the procedures established in the NTE INEN 1418 standard were carried out; in addition to the performance of the final product and its thickness.

2.5. Statistical analysis

Statistical analysis was based using IBM SPSS STADISTIC; here the ANOVA and Tukey statistical tests were performed. The use of the Tukey test occurred when there were significant differences between the results of the three procedures that did not allow the identification of the optimal procedure.

2.6. Industrial process design

The design of the industrial process began with the identification of all the variables involved in the procedure performed at the laboratory level, to which washing processes were added after each one as can be seen in figure 1.

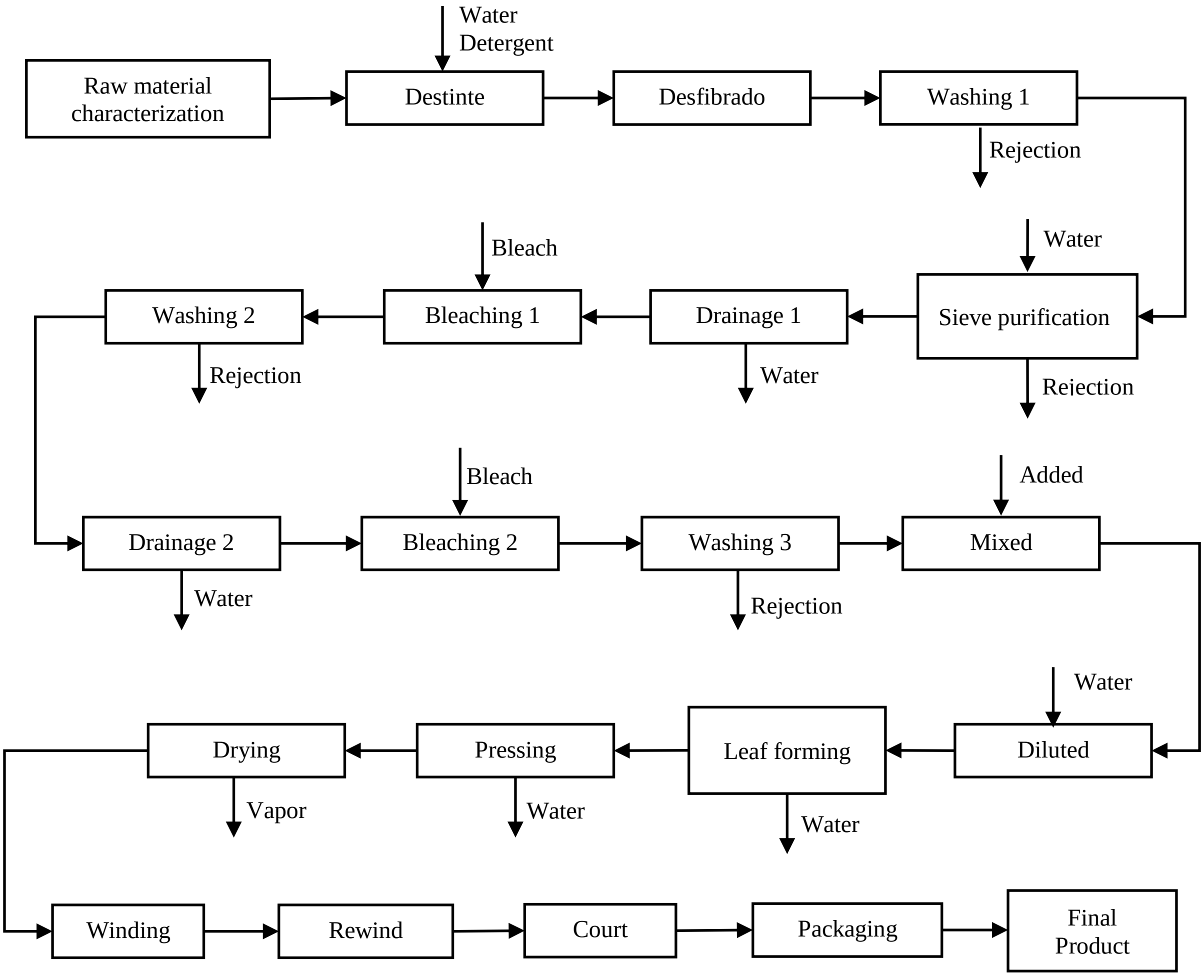

Figura 1: *Block diagram for toilet paper making*

With the variables identified, we proceeded to extrapolate the process at the industrial level. In addition to the mass balances, energy balances were made for the bleaching and drying processes.

The equipment sizing was carried out by determining the proportional volume according to the mass flow involved in each process, adding a safety factor of 20%. For tank-type equipment, its design was based on the design parameters exposed byMcCabe et al. (2007) :

Parameter	**Value**		
Velocity	20 – 150 rpm		
Proportions	$\frac{D_a}{D_t} = \frac{1}{3}$	$\frac{H}{D_t} = 1$	$\frac{j}{D_t} = \frac{1}{12}$
	$\frac{E}{D_t} = \frac{1}{3}$	$\frac{W}{D_a} = \frac{1}{5}$	$\frac{L}{D_a} = \frac{1}{4}$

Tabla 2: *Design parameters of turbine agitators*

In turn, its shape was elaborated by means of a geometric similarity to as shown in figure 2:

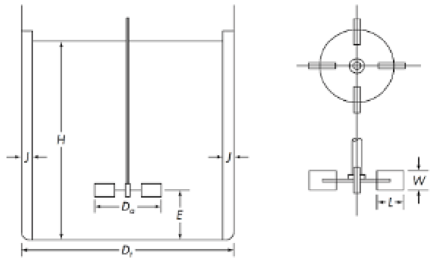

Figura 2: *Dimensions agitated tanks*

McCabe et al. (2007) Stable the power consumption of the agitator as follows:

$$P = N_P * n^3 * D_a^5 * \rho \qquad (1)$$

Where P is the power of the agitator, N P is the power number, n is the speed of rotation, D_a is the diameter of the tank and ρ is the density. For N_P it was necessary to use the Reynolds number for mixing.

In the case of the shredder, its volume was divided into two parts: the cylindrical part, and the truncated conical part that covers 20% of its total volume. The parameters of its rotor were fixed by similarity for equipment of the same load or volume.

For purification, the light of the sieves was calculated experimentally being 0.371 and 0.221, with proposed dimensions of 1x1.5x0.3 m, with a pyramidal part below where the residue accumulates. Similarly, the washing equipment worked with a ratio of 2:1 and 0.15 m thickness.

The roller type equipment was worked with proposed dimensions of 0.15 m for the radius and 2.4 m long, specifically in the case of the presser. For the training box, it was considered as a cube, so its dimensions were determined from the volume of work.

The length is the same as the press roller, the radius is determined from the heat supplied for evaporation considering it as an adiabatic system. According Road (2013) to heat transfer from the cylinder to the paper is given by:

$$Q_s = \frac{T_v - T_{p,prom}}{\frac{e_s}{k_s} + \frac{e_c}{k_c} + \frac{1}{h_p * \varphi}} * A_c (2)$$

Where, A_c is the area of the cylinder; T_v is the Vapor temperature; $T_{p,prom}$ average paper temperature; e_s the thickness of the condensate and e_c thickness of the cylinder being 6 and 38 mm respectively ;(Road 2013) k_s conduction coefficient of condensate of 0.682 W/m°C, and k_c conduction coefficient of cylinder15.6 W/m°C ;(Cengel 2007) of h_p paper convection coefficient 568.12 W/m^2°C; φ surface fraction of contact between cylinder and paper (0.5).

3. ANALYSIS AND RESULTS

3.1. Optimal process selection

The selection of the ideal procedure is based on three fundamental aspects: compliance with the INEN 1430 standard, low values in the additional parameters except for performance, and finally, high performance. The values obtained in the determination of the quality parameters remained within the established by the NTE INEN 1430 standard for paper, as can be seen in Table 3, although they are relatively high considering that it is a sheet of one layer. In the case of procedure 2, a high resistance can be noted, despite having a low grammage, this may be due to the action of starch, since, as mentioned, this Velasquez et al. (2010)additive provides a reinforcement in the interfiber joints of the cellulose pulp which confers greater resistance to the paper.

Parameter	**Procedure 1**	**Procedure 2**	**Procedure 3**	**NTE DESCENDING 1430**	**Unit**
pH	9.05	8.33	8.49	-	-
Humidity	14.853	9.985	23.276	-	%
Thickness	0.14	0.18	0.3	-	mm
Weight	33.3	31.1	36.95	Min. 19.0 Max.---	g/m^2
Resistance to breakage	146.13	182.67	249.33	Min. 50.0 Max.---	N/m
Absorption time	9.55	15.16	22.42	Min. --- Max. 50	s
Dimension	10 x 9.2	10 x 9.2	10 x 9.2	10 x 9.2	Cm
Yield	52.54	56.28	57.32	-	%

Tabla 3: *Quality parameters with the NTE INEN 1430 standard*

Another important point to take into account is the resulting pH level since this is directly related to the useful life, being the pH papers close to 7 those that have the best chance of life, while those with a pH of between 7 to 8 have a potential for long life (León and Fuentes, 2012). The procedure that mostly comes close to these conditions is number 2 with a value of 8.33. The low yield value may be due to the sieve used for washing the pulp during the process since the use of sieves with relatively high diameters allows the considerable passage of fiber, in addition the leaf formation bed is considered a possible source of loss. To avoid this problem you can work with meshes of diameter less than 0.850 mm, however, it must be taken into account that a smaller diameter of the sieve infers longer times in washing and a possible plugging of the mesh so it would be necessary to implement additional agitation force.

The ANOVA test was performed to verify significant differences between processes. From these values (Table 4) it can be concluded that, with the exception of performance, all quality parameters present significant differences in at least two of the three procedures performed due to a $p \leq 0.05$, so an additional test is necessary, which in this case is the TUKEY test.

		Sum of squares	Gl	Quadratic mean	F	Itself.
Weight	Inter-groups	86.448	2	43.224	13.019	.001
	Intra-groups	39.842	12	3.320		
	Total	126.290	14			
Resistance to longitudinal tensile rupture	Inter-groups	27381.484	2	13690.742	6.129	.015
	Intra-groups	26803.470	12	2233.623		
	Total	54184.954	14			
Absorption time	Inter-groups	415.891	2	207.945	198.040	.000
	Intra-groups	12.600	12	1.050		
	Total	428.491	14			
pH level	Inter-groups	1.416	2	.708	5.051	.026
	Intra-groups	1.682	12	.140		
	Total	3.097	14			
Humidity percentage	Inter-groups	452.166	2	226.083	164.840	.000
	Intra-groups	16.458	12	1.372		
	Total	468.624	14			
Thickness	Inter-groups	.069	2	.035	5.200	.024
	Intra-groups	.080	12	.007		
	Total	.149	14			
Yield	Inter-groups	63.426	2	31.713	.916	.426
	Intra-groups	415.354	12	34.613		
	Total	478.780	14			

Tabla 4: *ANOVA test results*

The results of the TUKEY test for each quality parameter are shown in the following tables:

Type of procedure	**N**	**Subset for alpha = 0.05**	
		1	**2**
Procedure 2	5	31.1260	
Procedure 1	5	33.3080	
Procedure 3	5		36.9460
Itself.		.183	1.000
The means for the groups in the homogeneous subsets are shown.			
to. Use the sample size of the harmonic mean = 5,000.			

Tabla 5: *Results for the Tukey test grammage*

Type of procedure	**N**	**Subset for alpha = 0.05**	
		1	**2**
Procedure 1	5	146.1340	
Procedure 2	5	182.6640	182.6640
Procedure 3	5		249.3320
Itself.		.463	.106
The means for the groups in the homogeneous subsets are shown. to. Use the sample size of the harmonic mean = 5,000.			

Tabla 6: *Tukey Test Longitudinal Tensile Breaking Strength Results*

Type of procedure	**N**	**Subset for alpha = 0.05**		
		1	**2**	**3**
Procedure 1	5	9.5580		
Procedure 2	5		15.1560	
Procedure 3	5			22.4200
Itself.		1.000	1.000	1.000
The means for the groups in the homogeneous subsets are shown. to. Use the sample size of the harmonic mean = 5,000.				

Tabla 7: *Tukey Test Absorption Time Result*

Type of procedure	**N**	**Subset for alpha = 0.05**	
		1	**2**
Procedure 2	5	8.3320	
Procedure 3	5	8.4960	8.4960
Procedure 1	5		9.0500
Itself.		.772	.088
The means for the groups in the homogeneous subsets are shown. to. Use the sample size of the harmonic mean = 5,000.			

Tabla 8: *Tukey pH Level Test Results*

Type of procedure	**N**	**Subset for alpha = 0.05**		
		1	**2**	**3**
Procedure 2	5	9.9856		
Procedure 1	5		14.8530	
Procedure 3	5			23.2766
Itself.		1.000	1.000	1.000
The means for the groups in the homogeneous subsets are shown. to. Use the sample size of the harmonic mean = 5,000.				

Tabla 9: *Tukey test humidity percentage result*

Type of procedure	**N**	**Subset for alpha = 0.05**	
		1	**2**
Procedure 1	5	.1400	
Procedure 2	5	.1800	.1800
Procedure 3	5		.3000
Itself.		.725	.091
The means for the groups in the homogeneous subsets are shown. to. Use the sample size of the harmonic mean = 5,000.			

Tabla 10: *Tukey testthickness result*

As can be seen, procedures 1 and 2 present similarity in most of the quality parameters in addition to having a low value, unlike procedure 3 that is far from the others so it is discarded. Between procedure 1 and 2, the highest performance is 2, so it is identified as the optimal for the development of the work.

3.2. Industrial process and economic analysis

A mass flow of 261.04 kg / day was established, a value determined from the data exposed in the environmental report N.- 004-UTGA-2021, provided by the EMMAIPC (Empresa Pública Municipal Mancomunada de Aseo Integral de Cañar Biblián El Tambo y Suscal). Where 146.92 Kg/day of final product, 5.88 Kg/day of chemical aggregates and a total rejection of 120 Kg/day were obtained.

Figure 3 shows the distribution of the process by the equipment involved, where a mass balance was made by components. It should be noted that the rejection rate was divided into the washing and purification processes: for the washing operation, the rejection of 4% of the dry raw material is considered, a value based on the percentage of rejection taken by ; in the purification operation, the dry rejection of the washing is subtracted from the general dry rejection of the process, For this, the three washing processes and the purification process are taken into account.Vasconez (2018) Table 11 indicates the process along with the operating flow with which it works, in addition to the composition, considering x_s as solid components, and a x_A as liquid component. While in table 12, you have the results of the energy balance carried out in the bleaching and drying processes.

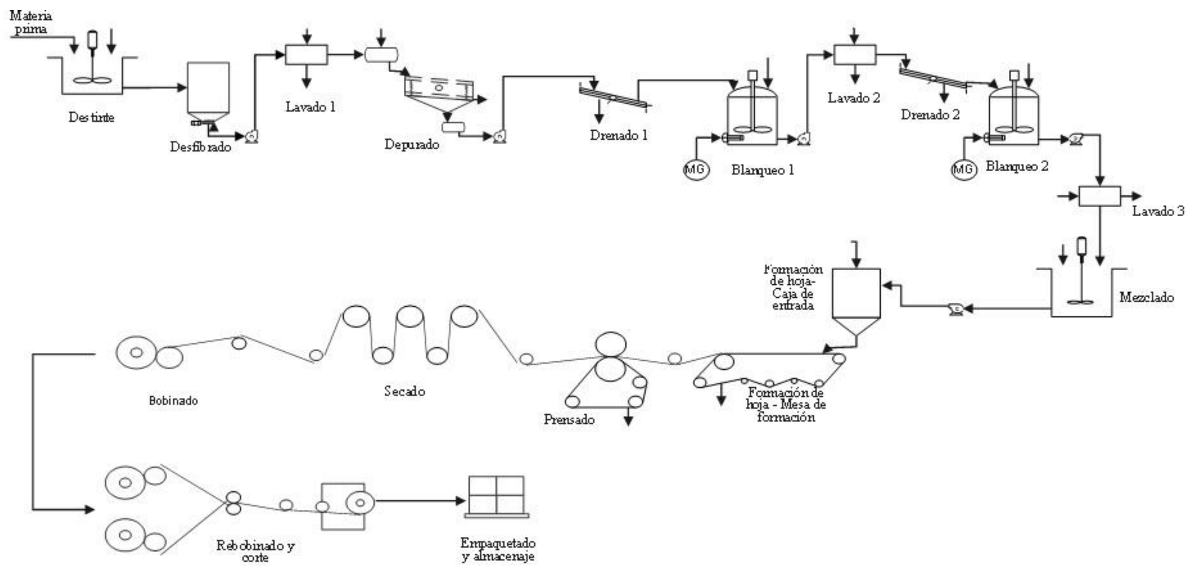

Figura 3: *Process flow diagram*

Process	Value	Unit	Composition
Destinte	3839.03	kg/day	x_A=0.94; x_s=0.06
Washing	3839.03	kg/day	x_A=0.94; x_s=0.06
Refined	18275.18	kg/day	x_a=0.99; x_s=0.01
Drainage 1	18236.8	kg/day	x_A=0.992; x_S=0.008
Bleaching 1	1812.63	kg/day	x_A=0.92; x_s=0.08
Washing 2	1812.63	kg/day	x_A=0.9205; x_s=0.0795
Drainage 2	1696.78	kg/day	x_A=0.9205; x_s=0.0795
Bleaching 2	1356.77	kg/day	x_A=0.9; x_S=0.1
Washing 3	1356.77	kg/day	x_A=0.9006; x_s=0.0994
Mixed	6576.47	kg/day	x_A=0.98; x_S=0.02
Diluted	13152.94	kg/day	x_A=0.99; x_S=0.01
Paper forming	13152.94	kg/day	x_A=0.9109; x_s=0.0891
Pressing	1476.2	kg/day	x_A=0.8205; x_s=0.1795
Drying	1476.2	kg/day	x_A=0.8205; x_s=0.1795

Tabla 11: *Operation flows by process.*

Flow	Value	Unit
Heat added to bleaching tank 1	71702.14	KJ/day
Heat added to bleaching tank 2	158484	KJ/day
Heat added to drying equipment	1527313.13	KJ/day
Steam mass	732.24	Kg/day

Tabla 12: *Energy balance*

With these data, we proceeded to carry out the sizing in the equipment, results of which can be seen in table 13 along with an estimate of the power consumption of some of them.

De-inking, bleaching and mixing tank					
Variable	**Detinting tank**	**Bleaching equipment 1**	**Bleaching equipment 2**	**Mixing tank**	**Unit**
$V_{operational}$	0.289	0.127	0.092	0.467	m^3
Equipment height	0.72	0.54	0.48	0.84	m
D_t	0.72	0.54	0.48	0.84	m
D_a	0.24	0.18	0.16	0.28	m
H	0.72	0.54	0.48	0.84	m
j	0.06	0.05	0.04	0.07	m
And	0.24	0.18	0.16	0.28	m
In	0.048	0.036	0.032	0.056	m
L	0.06	0.05	0.04	0.07	m
T	1.08	0.81	0.72	1.26	m
Power consumption	2.9828	2.9828	2.9828	2.9828	kWh/day

Desfibrador		
Variable	**Value**	**Unit**
volume	0.5357	m^3
Rotor diameter	400	mm
Height of the cylindrical part	1.05	m
Height of the truncated part	0.4233	m
Energy consumption	64.75	kWh/day

Washer				
Variable	**Washer 1**	**Washer 2**	**Washer 3**	**Unit**
Volume	0.2885	0.1271	0.0846	m^3
Height * Width * Length	0.15*1.96*0.98	0.15*1.30*0.65	0.15*1.06*0.53	m^3

Sieve scrubber			
Variable	**Top sieve**	**Bottom sieve**	**Unit**
Light	0.371	0.221	in
Volume	0.57		m^3
Length * Width	1*1.5		m^2
Rectangular height	0.304		m
Pyramidal height	0.3		m

Prensador		
Variable	**Value**	**Unit**
Radio	0.03 - 0.15	m

Leaf formation		
Variable	**Value**	**Unit**
Height in box	0.5986	**m**
Width * Length	2.3 * 5	m^2
Rotor speed	13.708	rpm
Power	17.02	Kwh

Roller dryer		
Long	2.4	m
Radio	0.462 - 0.5	m

Tabla 13: *Equipment sizing*

For the economic analysis, an investment of $ 47,059.65 was considered, value established from an estimated price of the main, service and transport equipment such as pumps and pipes. And an annual net income of $ 18,308.81, to establish this value a total of $ 110607.15 was assumed for sales, considering a unit value per roll of $ 0.15, with a weight of 51.55 g / roll; a tax value of $ 24,318.59; and $ 67,911.65 forexpenses such as raw material, additives, energy expenditure, water consumption and human resources.

The value of the NPV calculated is 5256.51 from the indicated investment, an annual recovery rate equivalent to net income and a discount rate estimated at 15%. As for the IRR, a value of 20% was obtained, this being higher than the discount rate. In addition to this, a recovery period of approximately 4 years was estimated.

4. CONCLUSIONS

In the elaboration of toilet paper, three different procedures were proposed based on data obtained through literature review, for this, it was deduced that the optimal way to approach the procedures was to divide the general process into two subprocesses: obtaining the pulp and the formation of the sheet. The difference for each procedure lay in the stage of obtaining the pulp on which the characteristics of the final product depend.

The data obtained during the performance of the three procedures are within the parameters established by the NTE INE 1430 standard. However, based on the results obtained from the ANOVA and Tukey tests, the second procedure could be optimally established as the most suitable for its performance of 56.282%.

We proceeded to make the relevant engineering diagrams, which allowed to identify the variables that interfere during the process. In addition, it helped identify the equipment that is necessary for the proper functioning of the system, these started from the mass and energy balances, which served to identify the volumes and the necessary power of the equipment.

Finally, it can be established that the project is profitable with a relatively short recovery period, this statement is due to the fact that the value of the NPV turned out to be positive which indicates that the project generates profits in the established period, in addition, the value of the IRR was found higher than the assumed discount rate which indicates that the project is profitable up to 20% in the discount rate.

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