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Technological improvement with solar assistance for starch extraction

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Abstract.

This project develops a solution for the processing of starch, taking into account the socio-economic aspects of the small-scale starch producers in Colombia. The proposed idea pretends to design a cheap and efficient system, which reduces the water consumption and the time of the sedimentation process, and does not require to be powered by the electricity network because it is managed with a solar pump.

The purpose is to implement a productive and sustainable technology, capable of being easily replicated in isolated communities with low water and electric supply.

Key words

Starch; photovoltaic systems; hydrocyclone; isolated community; technology transfer.

1. Introduction

The starch production in Colombia is one of the most important and traditional agricultural activities in high-altitude rural regions. However, their rudimentary techniques do not allow the small-scale producers to compete with other products due to the unstable and low production. Consequently, the intention of this project is to implement a cheap and efficient technology, which makes these agricultural communities been able to have a high productivity and guarantee their food-security.

The case of study in this project was made with sago starch. Sago (*Canna edulis*) is a plant cropped in the Andean Region, from whose roots the starch is extracted. This starch is mainly used for the preparation of food. The Colombian sago starch production is handmade, so that it is based on empirical knowledge.

It has been studied other technologies with the purpose to improve the starch extraction [3], [5], [9]. A hydrocyclonic separation process was first developed by Cerquera [3] concluding by mean of laboratory test that a hydrocyclone would be an effective solution reducing the time and increasing the productivity since it reduces the time in contrast with the traditional sedimentation process.

The hydrocyclonic operation will replace a step of the traditional sago starch extraction known as "washing" in which the starch is sedimented in pans shown in Figure 1. The entire separation process takes approximately one hour, and consumes 600 liters of water per 25 kilograms of product; the time used for this process and the high consumption of water reduces the productivity and increases the processing time.

This solution is going to be implemented first for a group of producers located in Pasca (Cundinamarca).

Fig.1. Small-scale producers in Pasca (Cundinamarca, Colombia)

A photovoltaic system was also implemented to feed electrically the first one, due to the scarce and low-quality electric network in contrast with the high levels of solar radiation in the place.

This project implements an alternative for the extraction of starch with the implementation of a hydrocyclonic system powered with a photovoltaic system, taking into account the limited technology and low productivity of the small-scale producers in Colombia. The Colombian small-scale starch producers have difficulties during processing due to low quality and high cost production. All these problems are a direct consequence of non-optimized operations and poor electricity supply because of their limited socioeconomic situation. On the other hand, water and electricity are also items that affect the cost and the productivity, since they are fundamental resources for the operation.

To achieve this goal the authors have determined that best solution is to:

- Design and construct a hydrocyclonic system connected to a photovoltaic system as energy source.
- Study a photovoltaic solution that will be appropriate to the hydrocyclonic requirements and local conditions.
- Characterize the hydrocyclonic system with different operational regimes in order to employ this technology to other starch extraction procedures.
- Instruct the small-scale producers to replicate, operate and sustain these systems.

2. Materials and Method

A. Evaluation of the characteristics of the sago starch and efficiency of the hydrocyclonic system

The evaluation of the sago starch is fundamental to implement and evaluate the performance and efficiency of the hydrocyclonic solution. The tests used for this evaluation are listed below:

- Settleable solids: a settleable solid test was implemented using the Standard Methods for the Examination of Water and Wastewater (SM 2540F). An Imhoff cone was used in the test to determine the percentage of starch in one (1) liter of suspension.
- Particle size: A particle size analyzer CILAS 1064, was employed in order to determine the mean particle size of the starch in the original suspension, and in the recovered suspension to verify the efficiency of the hydrocyclone.
- Density of the starch: It was used the value reported by Cerquera [3] and verified with the Standard test methods for specific gravity of soil solids by water pycnometer (ASTM D854-58).

B. Hydrocyclonic System

Hydrocyclones are mechanical elements, which turn the pressure of a pump into centripetal acceleration, making the solids present in a suspension to be separated by differentiated trajectories. There are many ways for designing a hydrocyclone; in this case the dimensionless correlations proposed by Coehlo & Medronho [4] are used to unify both experimental and dimensionless factors for dimensioning the hydrocyclone. The dimensionless correlations are shown in the following equations (1)-(3).

$$Stk'_{50} * Eu = 0.0474\left[\ln\left(\frac{1}{R_f}\right)\right]^{0.742} * exp(8.96c) \tag{1}$$

$$Eu = 371.5 * Re^{0.116} * exp(-2.12c) \tag{2}$$

$$R_f = 1218\left(\frac{D_u}{D}\right)^{4.75} * Eu^{-0.3} \tag{3}$$

$$G'(x) = 1 - exp\left[-0.693\left(\frac{x}{x'_{50}}\right)^m\right] \tag{4}$$

Computations were made with the software EES©, to give a range of the best solutions with the given operational and physical conditions required by the sago starch producers. The Rietema cyclone-type relations are used for the geometric dimensioning of the entire device. Besides, it is proposed an entire system with tanks, pumps, piping and accessories to implement the entire system.

C. Photovoltaic System

For the hydrocyclonic arrangement, a photovoltaic system (PV) is proposed to pump the suspension into the hydrocyclone taking into consideration the location were the hydrocyclonic system is going to be installed (04°18′′ North 74°18′′ West) since the location is going to be an important factor for designing the entire system.

The PV system was designed considering the flow rate and the total dynamic head of the pumping system.

To evaluate the number of solar panels it was applied the method presented by Ibañez Plana [6]. It was calculated a slope of 10º and it was assumed that there is not any kind of shadows that diminished the performance of the devices to correct the solar irradiation.

3. Results

A. Design, construction and development of the hydrocyclonic system

According to the case of study, the consumption of water is approximately 2.4 m^3/h of water for 6 hours of work. Based on these data two design maps were made plotting the hydrocyclone body diameter in meters (D) vs. the reduced cut size in micrometers (x'_{50}) of the hydrocyclone. The parameters of the curves in both maps (Fig.2 & Fig.3) are the pressure drop in Pascals (ΔP), and the volume flow m^3/s (Q).

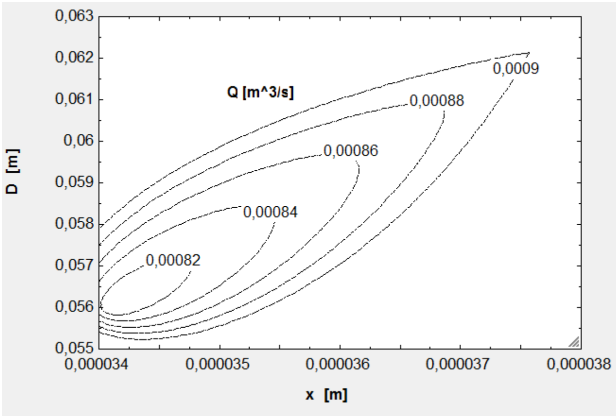


Fig.2. Design Map with volumetric flow variable.

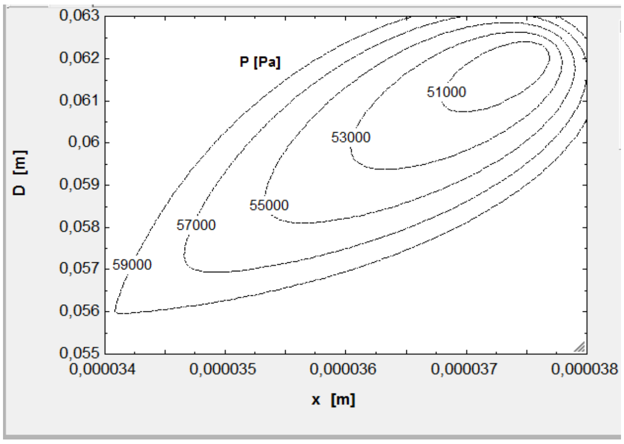


Fig.3. Design Map with pressure drop variable

With the design maps the geometry of the hydrocyclone was decided, considering a reduced cut size of 36 µm since it is a particle size lower than the mean size (45µm).

The plots of the maps were made using the hydrocyclone body diameter, with this parameter is possible to define the entire hydrocyclone geometry using the relations showed in the Figure 4.

Cyclone type	D_i/D	D_o/D	D_u/D	l/D	L/D	Cone angle degrees
Rietema[8]	0.28	0.34	0.20	0.4	5	20
Bradley[7]	0.133	0.20	0.07	0.33	6.85	9

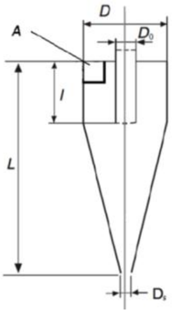


Fig.4. Hydrocyclone geometries. [10]

The geometry proposed for the hydrocyclone is showed in Table I.

Table I. Hydrocyclone Geometry for the case of study

Hydrocyclone Geometry	
D (cm)	5,6
Do (cm)	1,904
A (cm)	1,568
l (cm)	2,24
L (cm)	28
Ds (cm)	1,12

Due to the problems of the small-scale producers such as limited space, limited access to the electric network and low economic capacity for high technology installations, the hydrocyclonic system was implemented as shown in the Figure 5.

Fig.5. Hydrocyclonic system. Amplified image of the hydrocyclone (shown in the upper part at the left).

As shown in Figure 5, the hydrocyclone was connected with pipes and accessories to a pump so the suspension could be separated. The arrangement shown in Figure 5 is the first iteration of the system, since the last model will be electrically feed with a photovoltaic installation.

B. Characterization of the hydrocyclonic system

The tests mentioned in the methodology were used to determine the recovered solids by the implementation of the device for establishing the efficiency of the arrangement. The protocols used for determining the performance of the system showed that it is a viable alternative for an efficient, rational water usage, low-producer of dilute organic compounds and low-cost sago starch extraction.

The recovery comparison of the sago starch in the system is showed in the next figure, being the first container from left to right the original concentration of the process and the fourth container the sample with the biggest solid recovery. These tests were made varying the underflow valve as it is presented in table II.

Fig.6. Samples of sago starch recovered in the hydrocyclonic system.

A table from the settleable solids tests with the varying parameters is showed below:

Table II. Results of settleable solids tests for the hydrocyclonic system with a pressure drop in the hydrocyclone of 8,5psi.

Test	Sample	Percent (%)
1	Original Sample	1,5
2	8,5 psi completely opened underflow	23,5
3	8,5 psi completely opened overflow	4,7
4	8,5 psi half opening underflow	58,8
5	8,5 psi half opening overflow	4,8
6	8,5 psi recycled half opening underflow	60,5
7	8,5 psi recycled half opening overflow	1,8
8	Original Recycled Sample	3,7

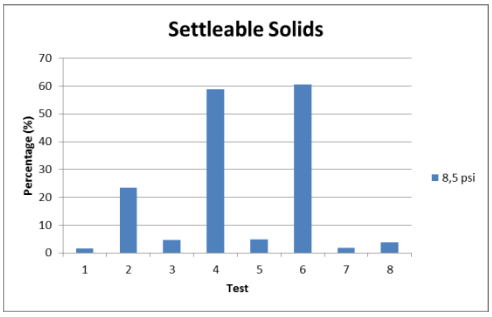


Fig.7. Settleable solids tests

The term recycled is used in the table II as the content recovered from the overflow orifice and pumped back again to the hydrocyclonic system. This step is beneficial because the losses of starch during the process are reduced to a minimum.

The particle size analyzer CILAS 1064 was also used to determine the experimental reduced grade of efficiency which mainly determines the probability of separation of a specific particle size.

The equation used to determine this parameter is showed in equation (5).

$$G'(x) = E_T \frac{dF_s(x)}{dF(x)} \tag{5}$$

In first place it was plotted the distribution of particle size from the underflow and the original sample as showed on Figure 8.

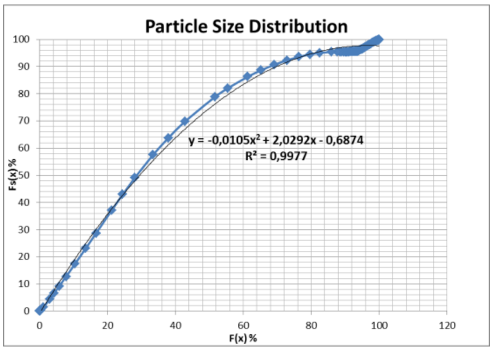


Fig.8. Particle size distribution

Once this plot is obtained it is possible to contrast the theoretical reduced grade of efficiency from equation (4) and the experimental reduced grade efficiency curve as showed in Figure 9.

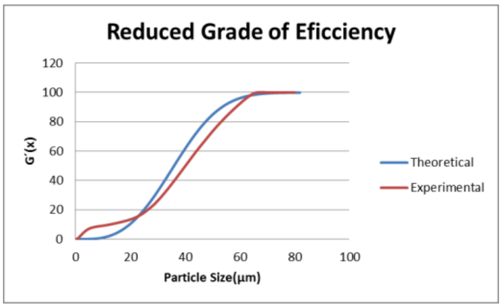


Fig.9. Reduced grade of efficiency curves.

C. Photovoltaic system

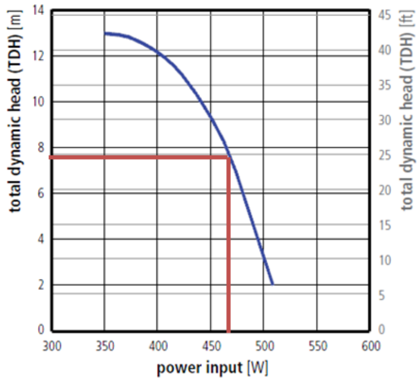
An annual analysis was made using the coordinates of the region in which the hydrocyclonic system was implemented (Yearly average solar radiation of 4.8kWh/m^{2}day [2]).

Table III. Daily Solar Radiation in Pasca (Cundinamarca)

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m^2/d	kPa	m/s	°C	°C-d	°C-d
January	19,2	76,60%	4,86	85,7	1,6	20,6	0	292
February	19,7	75,10%	4,83	85,7	1,7	21,4	0	277
March	19,7	78,80%	4,91	85,7	1,7	21,4	0	305
April	19,6	80,80%	4,65	85,7	1,6	21,2	0	289
May	19,4	79,70%	4,72	85,8	1,6	20,8	1	292
June	18,9	77,80%	4,83	85,9	1,9	20,2	2	267
July	18,9	70,80%	5	85,9	2	20,3	3	275
August	19,7	63,90%	5,07	85,9	1,8	21,4	0	303
September	20,2	65,00%	5,03	85,8	1,7	22,1	0	307
October	19,7	74,50%	4,7	85,8	1,5	21,4	0	302
November	19,2	81,10%	4,6	85,7	1,5	20,5	0	278
December	19	80,70%	4,6	85,7	1,7	20,2	0	286

It was determined that the hydrocyclonic system required 500Wp to power a solar pump of 8 meter of total dynamic head.

Therefore, it was obtained that the pumping system could function with 2 panels of 235 Wp.



TDH	PV generator	irradiation	flow rate					
			PV generator not tracked			PV generator single-axis tracked		
[m] / [ft]	[Wp]	[kWh/m²/day]	[m³/day]	[1,000 US Gal./day]	[1,000 Imp. Gal./day]	[m³/day]	[1,000 US Gal./day]	[1,000 Imp. Gal./day]
	340	4.5						
		6.0	6.0	1.6	1.3	9.0	2.4	2.0
		7.5	17.0	4.5	3.7	27.2	7.2	6.0
	400	4.5	3.0	0.8	0.7	4.3	1.1	0.9
		6.0	13.0	3.4	2.9	19.5	5.2	4.3
		7.5	26.0	6.9	5.7	41.6	11.0	9.2
8 m 26 ft	480	4.5	10.0	2.6	2.2	14.2	3.8	3.1
		6.0	24.0	6.3	5.3	36.0	9.5	7.9
		7.5	38.0	10.0	8.4	60.8	16.1	13.4
	600	4.5	20.0	5.3	4.4	28.4	7.5	6.2
		6.0	39.0	10.3	8.6	58.5	15.5	12.9
		7.5	56.0	14.8	12.3	89.6	23.7	19.7

Fig.10. Calculation of total dynamic head of the pumping system. [7]

The system does not require an energy storage system, since it will operate during 4 hours per day, and only in summer months, which agrees with the crop time.

D. In situ Results

The installation of the hydrocyclonic and photovoltaic system was made in two parts: first the installation of the solar panels, and second the installation of the solar pump and the hydrocyclonic system. The process can be seen in Figures 11-13.

Fig.11. Installation of the solar panels

Fig.12. Installation of the solar pump and the hydrocyclonic system in Pasca (Cundinamarca).

Fig.13. Panoramic view of the hydrocyclonic system (down) and photovoltaic system (up) connected together.

E. *Economic Analysis*

It was estimated the return on inversion of the project and it was concluded that given the water and time savings (200L per 25 kilogram of sago and approximately 3-4 hours per day respectively), the initial monetary inversion for the photovoltaic and hydrocyclonic systems can be recovered between the second and third year of use of this technologies given the monetary values of the savings mentioned before. The interest was set to the Colombian inflation rate (3,7%) and the daily payment (8 hours) in 10 USD considering a reduction of 3-4 hours on the daily basis.

Table IV. Return on Investment

Period (year)	Cash Flow (USD)	NPV (USD)	Summatory (USD
0	$ -5.042,46	$ -5.042,46	$ -5.042,46
1	$ 2.388,54	$ 2.310,00	$ -2.732,47
2	$ 2.388,54	$ 2.234,04	$ -498,43
3	$ 2.388,54	$ 2.160,58	$ 1.662,15

4. Discussion

As it was developed during the results section the solid recovery and the efficiency of the hydrocyclonic system, demonstrate that it is a viable solution with the aim of reducing the water consumption and optimizing the production of sago starch in Pasca (Cundinamarca).

The comparison between the theoretical and the experimental results show that the use of adimentional correlations is an effective approach to determine the size of the hydrocyclone. The cut size in the theoretical curve was set to 36µm in contrast with the experimental which was set at 40µm.

The differences between the theoretical and experimental curves are due to the differences in the parameters between the articles [1], [4] and the case of the study specifically from the density, concentration and particle size. Moreover, it was proved that the theoretical and experimental results match to each other; consequently, the starch recovery was successful.

With the conditions mentioned, the hydrocyclonic and photovoltaic systems were implemented in Pasca (Cundinamarca). It was possible to determine that 200 liters of water per 25 kilograms of roots can be saved.

The economic analysis was made in order to explain the small-scale producers in Pasca (Cundinamarca) of the benefits that they might get with the use of the hydrocyclonic system energized by a photovoltaic system.

As many other starches are used for industrial processes, such as the bioplastic production, it is expected to replicate this hydrocyclonic solution for the extraction of potato, cassava and corn starches in other projects developed by the Universidad de los Andes.

5. Conclusions

It has been tested the efficiency of the hydrocyclonic system for the sago starch production, pumped with a solar system and the performance of the photovoltaic system. The results show that these systems are efficient and economical solutions for the extraction of sago starch since they help to reduce the water consumption and it does not require a connection to the electrical network. It has been proved that this process improves the productivity and reduces the processing times in contrast with a normal gravitational sedimentation process; therefore, this system represents a technological advance that guarantees food security and a higher production.

This solution can also be applied for the separation of other starches.

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Nomenclature

A Area of the hydrocyclone entrance. (m^2)
c Concentration of solids at the entrance of the hydrocyclone. (%, v/v)
D_s Underflow Diameter (m)
D_o Overflow Diameter (m)
D Principal Diameter of the hydrocyclone (m)
E_T Total Efficiency.
Eu Euler Number (Pressure Loss Factor).
F(x) Distribution Frequency of the particle size at the entrance of the hydrocyclone. (%, μm/ μm)
F_s *(x)* Distribution Frequency of the particle size at the underflow of the hydrocyclone. (%, μm/ μm)
G´(x) Reduced Grade of Efficiency.
l Size of the cylinder in the hydrocyclone (m)
L Total size of the hydrocyclone. (m)
ΔP Pressure Drop. (Pa)
Q Volume Flow. (m^3/s)
Re Reynolds Number (Characterization of the Flow Movement).
Rf Relation of the Volume flow in the underflow and the overflow.
Stk Stokes Number (Behavior of Particles in a Suspension).
x Particle size. (μm)
x'_{50} *Cut* Size. (μm)

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