Technical proposal for the design of a helical conveyor for solid waste handling

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Article Info

ABSTRACT

The novelty of this work lies in the design of a helical conveyor for solid waste from the chocolate industry, materials that can be cohesive, with variable density, and potentially corrosive. The objective is to present a validated and replicable technical model that optimizes the transport of 5 metric tons per hour of these wastes at Peru's National Chocolate Company. The goal is to minimize human contact, improve ergonomic safety, and transform waste into exploitable resources under circular economy principles. The methodology employed is an applied type with a quantitative approach, supported by the selection of components through specialized technical catalogs from KWS manufacturing and Martin engineering, which implement ANSI/CEMA 350 standards. Results indicate a total required power of 1.5 HP, with a helicoid diameter of 9", a helical tube of 2", a pitch of 6", and operation at 60 RPM. It is concluded that this design constitutes an efficient and replicable technical solution to improve working conditions in industrial environments, significantly reducing occupational injuries while mitigating environmental impact.

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1. INTRODUCTION

Efficient management of solid waste is a significant challenge in diverse industries, especially in the environmental and industrial sectors. To date, workers in the industry continue to manually handle solid waste with shovels, exposing them to risks such as injuries and contamination [1]. Solid waste workers commonly suffer musculoskeletal disorders such as low back pain due to repetitive physical activities and heavy load lifting [2]–[4]. They also suffer respiratory conditions from exposure to bioaerosols and endotoxins [5], [6] and skin problems such as irritation, cracking, and fungal infections [7], [8]. Helical conveyors represent the ideal solution for moving difficult-to-transport materials, including irregular solids and semi-liquid materials such as waste in food processing and sediments in water treatment [9], [10]. Furthermore, it has been demonstrated that helical conveyor systems can be configured for various applications, with specific designs to improve structural resistance and reduce friction [11], [12]. The technological evolution of helical conveyors has been the subject of numerous investigations that establish the basis for their design and optimization in solid waste handling applications. Bulgakov *et al.* [13] have demonstrated that the decisive influence of transported material characteristics on structural parameters is critical for system performance, particularly when analyzing dynamic loads that can exceed the critical maximum torque by up to 70% during sudden braking processes. Studies by Karwat *et al.* [14] have shown

that traditional theoretical methods underestimate actual power requirements during operation, noting that multi-objective optimization allows identification of larger helicoid diameter and pitch configurations that provide maximum efficiency with minimum energy demand, thus reducing mechanical wear. The selection of appropriate materials, such as 304-316L stainless steel, is fundamental according to Henriques *et al.* [15], who have verified that these materials offer high resistance to corrosion and mechanical stress under demanding conditions. ANSI/CEMA 350 recommendations establish correction factors for equivalent capacity considering elements such as special pitch, helicoid type, and number of paddles [16]. For their part, Rucins *et al.* [11] have identified that torque depends significantly on the fixed cover diameter and the conveyor fill factor. Coranic and Mascenik [16] have validated through structural resistance analysis that properly dimensioned components maintain optimal safety factors between 1.80 and 15, avoiding deformations under Von Mises stress even in critical load zones.

In contrast with research focusing on conventional material transport methods such as powder [17], [18], small or bulk materials [16], [19], [20], even viscous and liquid materials [15], widely used in food, chemical, pharmaceutical, agricultural, metallurgical, construction, and wood industries [15], [16], [21] there is an identified need to develop solutions specifically oriented to solid waste handling. This need arises from the limited availability of updated literature on the application of the helical conveyor as an effective alternative to reduce the risk of ergonomic injuries and illnesses derived from continuous physical effort and prolonged exposure to residual materials. Inefficient manual handling of these wastes not only generates operational risks but also represents a critical barrier to implementing circular economy and sustainability strategies [22]. The inability to handle the waste flow in an automated and safe manner prevents its proper segregation and valorization, resulting in workplace contamination [23]–[26] and hindering its potential reuse in processes such as composting, bioenergy generation, or byproduct recovery. Therefore, an efficient transport system is the first step to integrate these wastes into a sustainable value chain.

The present work consists of the design of a horizontal helical conveyor with a capacity of 5 metric tons per hour, applying standardized technical specifications, implemented through the helical conveyor engineering guide from KWS manufacturing [27] and the technical catalog from Martin engineering [9], both founded on conveyor equipment manufacturers association (ANSI/CEMA 350) guidelines [16]. The main objective is to optimize the transport of solid waste, minimizing human contact, improving ergonomic safety, and mitigating environmental impact at Peru's National Chocolate Company. Additionally, 304L stainless steel is employed, a material known for its corrosion resistance [28]. This system not only responds to the company's specific needs but also establishes the foundation for replicable applications in other industries.

2. THEORETICAL FRAMEWORK

2.1. Calculation of power in idle

The power in idle (1) represents the energy required to overcome friction in the helical conveyor system without a material load. For its determination, multiple factors are considered. Including conveyor length (L), operating speed (N), helicoid diameter factor (F_d), and hub factor (F_b) [9].

$$HP_f = \frac{L x N x F_d x F_b}{1,000.000} \tag{1}$$

2.2. Calculation of power to transport material

The calculation of power to transport material, given by (2), represents the amount of energy that the motor must supply to move the material from the feed hopper to the discharge. The estimation of this power is based on variables such as the system's transport capacity (C), conveyor length (L), material density (W), and various correction factors, which include the material factor (F_m), the helicoid type factor (F_f), and the paddle factor (F_p) [9], [16]. Subsequently, a power correction factor is applied [9], given that each power involves a load inherent to the conveyor.

$$HP_m = \frac{C x L x W x F_f x F_m x F_p}{1,000.000} \tag{2}$$

2.3. Calculation of total power and critical torque

The drive power in a helical conveyor (3) determines the energy necessary to operate the system, considering the idle power to overcome friction and the power to move the material, adjusted by the system efficiency (e) and overload factor (F_0) [9]. In parallel, critical torsional capacity is calculated to ensure that mechanical components, such as the shaft and helical tube, can withstand torsional loads without failing. Critical torque (T) (4) is calculated using hp (total power) and N (operating speed in revolutions per minute).

$$HP_{total} = \frac{HP_f + HP_m}{e} \times F_0 \tag{3}$$

$$T = \frac{63025 \times hp}{N} \tag{4}$$

2.4. Component selection for helical conveyors

Martin's catalog is largely founded on the guidelines and specifications established by ANSI/CEMA 350, reflecting widely accepted industrial standards for the design, selection, and construction of such material handling equipment. Once the design parameters are calculated, all system components are selected using the technical tables from that catalog. For selecting the helical shaft, designed to resist high mechanical stress, torsional strength, and manufacturing material are considered. The helical tube acts as the helicoid support and provides stability to the transport system, and the coupling bolt has been dimensioned based on the helical shaft. The integration of these three elements within the helical conveyor ensures stable operation, extends the system's service life, and optimizes load transfer, minimizing energy losses.

On the other hand, the flange for tubular trough, tubular trough, and cap for tubular trough form the structural assembly that encloses the helicoid and transports material, allowing safe and efficient operation within the conveyor. Their selection has been based on the helicoid diameter. The helicoid constitutes the central component of the helical conveyor, being responsible for displacing material along the system with efficiency and stability. Its geometry was performed according to pitch, helicoid diameter, and helical tube diameter. Figure 1 shows the component selection for better visibility.
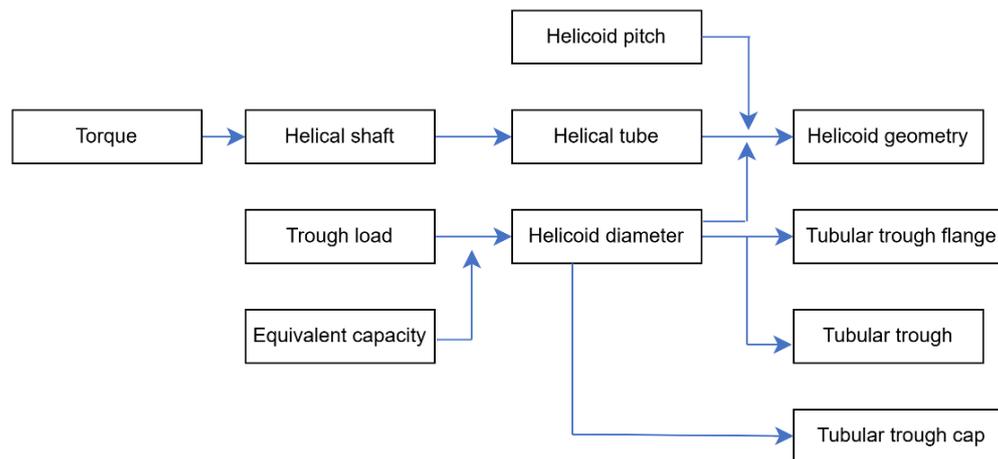

Figure 1. Selection of components

3. METHOD

The methodology was based on the ANSI/CEMA 350 standard, implemented through two references. The methodology was founded on the ANSI/CEMA 350 standard, implemented through two complementary technical references: the helical conveyor engineering guide from KWS manufacturing and the technical catalog from Martin engineering. These resources enabled adequate component selection, considering factors such as capacity, speed, and torque, optimizing helical conveyor performance. Its approach is quantitative, focusing on the collection and analysis of numerical data [29] to design a helical conveyor. The research is of an applied type, as it seeks to solve a practical problem [30] identified at Peru's National Chocolate Company. The design is descriptive, as the study does not manipulate variables directly but rather analyzes and documents the problem's characteristics [31]. Furthermore, the design focuses on creating a model based on predefined technical parameters. The design phase includes detailed stages such as problem analysis and material specification.

The first stage, problem analysis, consists of identifying the company's operational context and evaluating current waste transport methods to understand specific limitations and needs. Next, in the specification of design parameters, optimal values for capacity, power, torque, and speed are defined. In the materials and components selection stage, appropriate materials are chosen, such as 304L stainless steel, recognized for its corrosion resistance. Figure 2 presents the flow diagram of the company's waste management system, showing the integration of the proposed helical conveyor at each process stage, from waste generation in production areas to final disposal in agricultural zones.
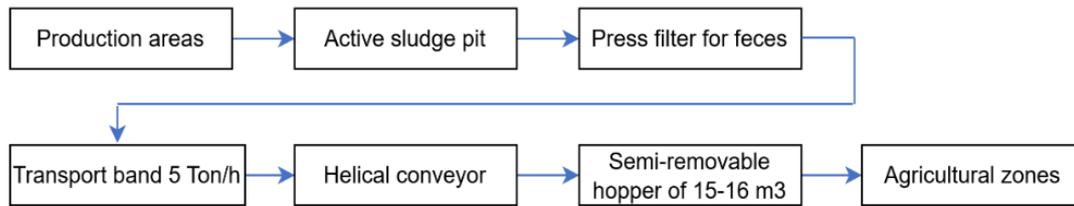
Figure 2. Selection of components

4. RESULTS
4.1. General information collected

The study addressed the design of a helical conveyor aimed at handling solid waste, specifically organic fertilizer. The types of solid waste handled include: general and/or ordinary waste (28.11%), plantas de tratamiento de aguas residuales (PTAR) sludge waste (90.40%), recyclable organic waste from exploitable and/or commercial processes (15.68%), recyclable packaging and containers of commercial nature (13.75%), and exploitable special waste (35.25%-50.25%). Within organic process waste are cacao and derivatives (5.35%), fochis (1.24%), cocoa (10%), derivatives (14.5%), chocopresto (1.68%), cookies (18.0%), panettone (24%), and creams (2.0%), with cookie and panettone production lines generating the largest quantity of solid waste and byproducts. The required system capacity was 5 metric tons per hour, equivalent to 220 ft³/h, and the transported material presented specific properties such as an apparent density of 50 lb/ft³, granular, medium abrasiveness, and slow flowability. These characteristics directly influenced component selection and helicoid design. The material operates at an average temperature of 25 °C, and due to its physical properties, 304L stainless steel was chosen for its high resistance to corrosion and wear. Equivalent capacity was calculated considering short pitch factors (CF1 =1.5), helicoid type (CF2 =1.0), and number of paddles (CF3 =1.0), resulting in 330 ft³/h. Conveyor speed, determined using the relationship between equivalent capacity and capacity at 1 rpm (C1 rpm =5.45 ft³/h) [9], [27] was calculated at approximately 60 RPM.

$$C_{req} = \frac{5\ ton/h}{50\ lb/ft^3} = \frac{11000\ lb/h}{50\ lb/ft^3} = 220\ ft^3/h$$

$$C_{equiv} = 220\ ft^3/h \times 1.5 \times 1.0 \times 1.0 = 330\ ft^3/h$$

$$N = \frac{330\ ft^3/h}{5.45\ ft^3/h} \sim 60\ rpm$$

With an equivalent capacity of 330 ft³/h and assuming a 30% trough load, the helicoid diameter is 9-inch (see Table 1) [27], and the helicoid pitch is 2/3 of the helicoid diameter, which equals 6" (see Table 2) [9].

Table 1. Helicoid diameter selection

Trough load	Helicoid diameter (in)	Capacity cubic feet per hour (full pitch)		Max. RPM
		A 1 RPM	A Max. RPM	
30%	4	0.41	50	130
	6	1.49	180	120
	9	5.45	545	100
	10	7.57	720	95

Table 2. Helicoid pitch selection

Capacity factors for conveyor with special pitch C_{F1}		
Pitch	Description	C_{F1}
Standard	Pitch = Helicoid diameter	1.00
Short	Pitch =2/3 Helicoid diameter	1.50
Medium	Pitch =½ Helicoid diameter	2.00
Long	Pitch =1 ½ Helicoid diameter	0.67

4.2. Calculation of power in idle

In this design, the conveyor length was established at 2.5 m, while the helicoid rotation speed was previously set at 60 RPM. On the other hand, the helicoid diameter factor, determined for a 9-inch helicoid, was 31.0, and the hub factor for the pendant was obtained as 1.7. Applying these values to (1) yields the following result:

$$HP_f = \frac{8.2x60x31x1.7}{1000000} = 0.026HP$$

This value indicates that the system requires 0.026 HP to keep the helicoid rotating without a load. This result is crucial, as any overestimation or underestimation in this calculation could affect motor selection, generating inefficiencies in power transmission and affecting equipment performance under real operating conditions.

4.3. Calculation of power to transport material

For this design, the equivalent conveyor capacity was calculated at 330 ft³/h, while the density of composted fertilizer was set at 50 lb/ft³. Likewise, the conveyor's effective length is 8.2 ft, and correction factors were set at 1.0, as special configuration helicoids or additional paddles were not employed. The power necessary to move the material was determined using (2).

$$HP_m = \frac{330x8.2x50x1.0x1.0x1.0}{1000000} = 0.135HP$$

However, to reflect the real load on the conveyor more accurately, a power correction factor for transporting material [9] was applied, which adjusted the final value to 0.25 HP. This adjustment is fundamental. The transported material may present variations in its cohesion and flowability, affecting the effort required for its displacement.

4.4. Calculation of total power and torque

The total power required for the helical conveyor's operation is obtained considering both idle power and power necessary for material transport. However, this calculation must also include additional factors that influence the system's actual demand, such as the overload factor and transmission efficiency factor. The overload factor (F_0) represents a safety coefficient that compensates for possible load fluctuations, particle impact, and unexpected accumulations in the system. For this design, the overload factor was set at 2.8 [9]. On the other hand, transmission efficiency (e) is a measure of the percentage of effective power transferred to the system after considering mechanical losses in gears, pulleys, and chains. In this case, it was determined according to catalog tables that transmission efficiency is 0.87, considering chain transmission is employed. With these parameters, total power and critical torque are obtained by applying (3) and (4).

$$HP_{total} = \frac{(0.026 + 0.25)x2.8}{0.87} = 0.89HP$$

$$T = \frac{63025x0.89}{60} = 934\ lbf - in$$

This value of 0.89 HP is applied with a safety factor of 1.5, resulting in approximately 1.5 HP, which allows optimal selection of the drive motor. This safety margin ensures that the motor operates within its efficiency range, avoiding overloads and reducing the risk of mechanical failures.

4.5. Determined mechanical components

The helical shaft has a nominal diameter of 1½ inches in (see Table 3) [27]. Allowing it to support a torsional load of 934.87 lbf-in, and its manufacture in 304L stainless steel provides high corrosion resistance. The helical tube with an interior diameter of 2 inches is secured to the helical shaft with a coupling bolt of 1/2 in diameter (see Table 4) [9].

Table 3. Helical shaft selection		
Helical shaft diameter	Shaft	
	Safe stress	Torque rating
	PSI	lbs. in
1	6,000	700
1½	6,000	2,600
2	6,000	6,500

Table 4. Helical tube selection		
Helical shaft diameter (in)	Helical tube (in)	Coupling bolt diameter (in)
1	$1^{1}/_{4}$	3/8
1½	2	1/2
2	$2^{1}/_{2}$	5/8
$2^{7}/_{16}$	3	5/8

With the helicoid diameter (H) data of 9 inches, helical tube (T) of 2 inches (50.8 mm), and pitch (P) of 6 inches (152.4 mm), the helicoid geometry was obtained. The major perimeter ($2P_M$) was determined as 28.9 in, minor perimeter ($2P_m$) as 8.7 in, and side as 3.5 in. The helicoid grade was established at 29.06°, with a major radius of 5 in and a minor radius of 1.5 in.

$$2P_M = \sqrt[2]{(H \times \pi)^2 + P^2} = \sqrt[2]{(9 \times \pi)^2 + 6^2} = 28.9 \ in$$

$$2P_m = \sqrt[2]{(T \times \pi)^2 + P^2} = \sqrt[2]{(2 \times \pi)^2 + 6^2} = 8.7 \ in$$

$$L = \frac{H - T}{2} = \frac{9 - 2}{2} = 3.5 \ in = 88.9 \ mm$$

$$X = 360 - \left[\frac{360 \times (2P_M - 2P_m)}{2 \times \pi \times L}\right] = 360 - \left[\frac{360 \times (28.904 - 8.688)}{2 \times \pi \times 3.5}\right] = 29.06°$$

$$R_{Helicoide} = \frac{2P_M \times L}{2P_M - 2P_m} = \frac{28.904 \times 3.5}{28.904 - 8.688} = 5 \ in$$

$$r_{Helicoide} = \frac{2P_m \times L}{2P_M - 2P_m} = \frac{8.688 \times 3.5}{28.904 - 8.688} = 1.5 \ in$$

Similarly, with the help of the technical tables from the catalog [9], the measurements of the other components were obtained, see Figure 3. The flange for tubular trough, used to connect the trough with other system components, was designed with a diameter of 10¾ in and its fastening is performed through 8 bolts of 3/8 inches diameter. The tubular trough, responsible for containing the helicoid and confining the transported material, was selected with a nominal diameter of 10 in. To complete the structure, a cap for tubular trough was incorporated, with an outer diameter of 13¼ in and thickness of 1/4 in, fastened through 8 bolts of 3/8 in diameter distributed.
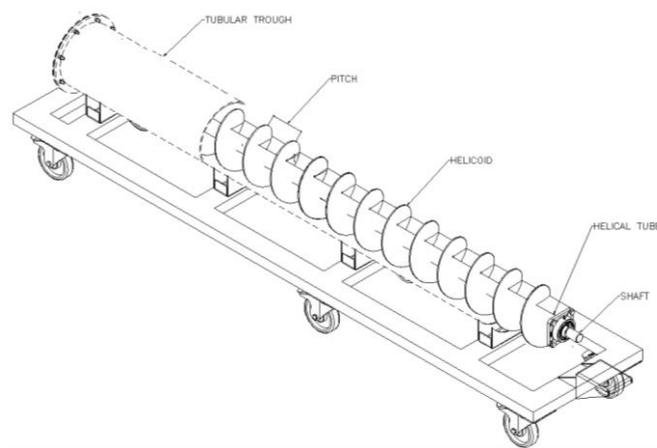

Figure 3. Helical conveyor components

5. DISCUSSION

The helical conveyor, designed to handle solid waste, demonstrates effective integration between technical parameters and material characteristics that optimize its performance. The selection of 304L stainless steel responds appropriately to operating conditions of 25 °C, confirming what Bulgakov *et al.* [13] stated about the decisive influence of material characteristics on structural parameters. The initial capacity of 5 metric tons/hour (220 ft³/h) aligns with ANSI/CEMA 350 recommendations [16] for materials with an apparent density of 50 lb/ft³ and slow flowability. The design methodology based on ANSI/CEMA 350 standards and Martin catalog reflects the systematic approach recommended by KWS Manufacturing [27], particularly in applying correction factors for equivalent capacity: special pitch (CF1 =1.5), helicoid type (CF2 =1.0), and number of paddles (CF3 =1.0). The calculated operating speed of 60 RPM represents, according to Karwat *et al.* [14], a balance between efficiency and minimization of wear.

The analysis of the helical conveyor design for solid waste reveals the critical importance of precise power calculation to ensure efficient operation. Idle power of 0.026 HP aligns with findings from Karwat *et al.* [14], who demonstrated that traditional theoretical methods underestimate power requirements and that minimizing energy consumption is essential to reduce operational costs. The determination of total power of 1.5 HP, incorporating an overload factor of 2.8 and transmission efficiency of 0.87, is consistent with models developed by Rucins *et al.* [11], who identified that torque depends significantly on fixed cover diameter and conveyor fill factor. The capacity of 330 ft³/h with material density of 50 lb/ft³ aligns with multi-objective optimization results presented by Karwat *et al.* [14], where conveyors with larger helicoid diameter and pitch (such as the proposed 9-inch design) provide maximum efficiency with minimal power demand, reducing mechanical wear and optimizing motor selection.

The helical conveyor design for solid waste handling reveals a robust and functionally efficient configuration. The selection of 304L stainless steel for the helical shaft aligns with recommendations from Henriques *et al.* [15], who demonstrated that materials with high corrosion and mechanical stress resistance are critical for conveyors operating under demanding conditions. The shaft diameter (1½ inches), coupling bolt (½ inch), flange (10¾ inches), tubular trough (10 inches), and cap (13¼ inches) have been appropriately dimensioned, significantly reducing failure risk. Structural resistance analysis demonstrates that properly dimensioned components maintain optimal safety factors (1.80-15), avoiding deformations and dangerous conditions under von mises stress [16], preventing failures even in critical load zones. The helix is fundamental to conveyor efficiency, being optimal when its speed equals the axial advance of material [32]. Its design directly affects system stability, allowing homogeneous movement and avoiding accumulations or deterioration in complex routes [13].

The helical conveyor study presents limitations. It focuses on horizontal design, overlooking vertical section particularities; furthermore, the absence of experimental validation and maintenance planning could generate discrepancies between theoretical and actual performance. The 5 ton/h helical conveyor design for solid waste in the chocolate industry offers important practical and theoretical contributions. Practically, it represents a solution that automates manual processes, improves ergonomic conditions for workers, optimizes industrial space use, and facilitates compliance with sanitary and environmental regulations. Beyond technical validation, the proposed design offers quantifiable operational improvements. The capacity of 5 metric tons/hour (equivalent to 220 ft³/h) enables processing a production shift's waste volume in drastically reduced time compared to manual methods. A reduction of nearly 100% in direct manual handling is projected, which would significantly decrease musculoskeletal disorders reported in literature [2]–[4]. The design's robustness, with 304L stainless steel components and appropriate safety factors preventing deformations, minimizes failure probability and thus unplanned downtime. Fundamentally, this conveyor acts as a key facilitator for waste valorization. By ensuring constant organic fertilizer flow, the system allows integration of this waste into large-scale composting processes, bioenergy production through anaerobic digestion, or direct packaging for commercialization as agricultural fertilizer, thus closing the materials cycle within a circular economy framework.

This work demonstrates how technical standards can be applied to solve real industrial problems, contributing to industrial automation and occupational safety improvement. The documented helical conveyor design offers valuable contributions for future development through its structured methodology under ANSI/CEMA 350, validated parameters (60 rpm, 1.5 HP, 120 N-m), establishing important precedents with 304L stainless steel selection for solid materials transport applications. Promising research areas include energy optimization, advanced monitoring systems, adaptations for diverse materials and applications in sustainability, while future studies could focus on wear analysis, computational simulation, Industry 4.0 integration, economic analysis, and specific sectoral adaptations, thereby establishing solid foundations for research that will improve efficiency and applicability of helical conveyors in diverse industrial sectors.

6.   CONCLUSION

The present study has developed a design for a helical conveyor for industrial solid waste handling of 5 Ton/h. Parameters were established, such as operating speed of 60 rpm, total power of 1.5 HP, and torque of 934.87 lbf-in, ensuring efficient and reliable operation. The mechanical design incorporated a helical shaft of Ø1 1/2 in and 2.5 m length, a helical tube with diameter of Ø2 in. The connection between these elements was performed through a coupling bolt of Ø1/2 in, ensuring robust connection. A tubular trough with nominal diameter of Ø10 was designed with a fastening flange of Ø10 3/4 in supporting a distribution of eight bolts of Ø3/8 in, a cap for tubular trough of 13¼ in fastened with 8 bolts of Ø3/8 in. Additionally, the helicoid was dimensioned with diameter of Ø9 in, pitch of 6, helicoid grade established at 29.06°, with major radius of 5 in and minor radius of 1.5 in. As future research directions, the following are recommended: first, integration of Industry 4.0 technologies, such as IoT sensors, will enable real-time monitoring of critical parameters such as torque and temperature, enabling predictive maintenance that

maximizes operational efficiency and minimizes energy consumption. Secondly, promote development of modular and adaptive designs offering versatility, allowing easy system reconfiguration for different lengths, inclinations, and waste types. Finally, conduct life cycle analysis to quantify environmental impact.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

The authors declare that the study did not involve human participants.

ETHICAL APPROVAL

The authors declare that the study did not involve human or animal participants.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [JASA], upon reasonable request

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