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DESIGN AND OPTIMIZATION OF AN ACTIVATED CARBON HANDLING SYSTEM FOR IMPROVED GOLD RECOVERY

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ABSTRACT

Gold mining is a crucial industry in Zimbabwe, playing a significant role in the country's GDP. Despite facing various challenges such as low productivity and illegal activities, it remains an essential sector. One prominent player in the Zimbabwean gold mining sector, with a long history since the 1890s, is currently experiencing issues at their plant. These problems include carbon losses, time wastages, environmental hazards, and safety risks for workers. This project aims to create a mechanical activated carbon handling system for gold recovery at the plant. The system comprises a carbon column, stripping column, cleated conveyor belt, and gantry. Through a 5-step methodology and concept generation, a final concept was selected using decision matrices. The chosen concept allows for the handling of activated carbon in a slurry mixture, making transportation to the regeneration plant easier. The inclusion of a cleated conveyor belt and gantry ensures efficient and safe movement of activated carbon, while an integrated Arduino control system monitors and controls carbon flow, reducing potential losses. By addressing the challenges faced by the company, this mechanical activated carbon handling system improves efficiency and sustainability in the gold recovery process, thereby contributing to the overall productivity of Zimbabwe's gold mining sector.

Keywords: Gold Mining, Carbon Losses, Activated Carbon Handling, Efficiency, Sustainability.

I. INTRODUCTION

Activated carbon, also known as activated charcoal, is widely used in the gold mining industry to extract gold from ore through a process called leaching. However, the handling of activated carbon presents several challenges, including value and time losses, health risks, and environmental hazards [1]. One prominent gold mining and processing company, referred to as "XYZ Mine," faces a significant issue during the transfer of activated carbon from adsorption tanks to the stripping column. Currently, this process involves manual collection and rinsing of activated carbon using a handheld hose pipe, leading to value and time losses, and exposing workers to hazardous substances like caustic soda, nitric acid, and cyanide.

Exposure to these chemicals can cause various health issues, including skin and lung irritations, coughing, and even life-threatening conditions like lung and skin cancer with prolonged exposure to sodium cyanide. While the organization provides personal protective equipment, the high work-labor ratio increases the risk of workers being exposed to toxic substances and developing musculoskeletal disorders.

To address these challenges, this research paper aims to propose a solution for the mechanical handling of activated carbon in the gold recovery process at XYZ Mine. The objective is to design a system that minimizes value and time losses, reduces health risks, and ensures environmental safety. By implementing an efficient and safe handling system, the overall efficiency and sustainability of the gold recovery process can be enhanced, contributing to the productivity of the gold mining industry.

II. LITERATURE REVIEW

In gold recovery processes, activated carbon plays a crucial role in adsorbing gold from solution. After adsorption, the carbon becomes filled with gold and needs to be handled and processed for further gold recovery. Material handling equipment can be categorized into five major categories based on specific job requirements [1]. These categories include transport equipment, positioning equipment, unit load formation equipment, storage equipment, and control systems. Each category serves a specific purpose in the handling and movement of materials.

Transport equipment is used to move materials from one location to another within the elution plant. Conveyors, cranes, and industrial trucks are commonly used in transport systems. Conveyors are suitable for frequent material movement over fixed paths, while cranes offer flexible movement within restricted areas. Industrial trucks provide versatility in handling materials over variable routes [2, 3].

Positioning equipment is used to fix or position materials at specific locations within the elution plant. Vibrating screens and chutes are commonly used in positioning materials. Vibrating screens are used for de-slurring and dewatering of activated carbon, while chutes are used for the transfer of materials to lower levels.

Unit load formation equipment is used to restrict or direct materials to maintain their integrity during handling and transportation. Bags and bulk load containers are commonly used for unit load formation. Bags are inexpensive and convenient for short-term storage, while bulk load containers allow efficient handling of larger quantities of materials. Storage equipment is used to buffer materials for a defined period [5, 6]. In the elution plant, storage may be required between specific points. Bins with chutes are commonly used for storage, as they are cost-effective and easy to maintain.

Control systems manage and regulate the behavior of devices or systems. They can be classified as open loop control systems or closed loop control systems. Open loop control systems utilize a controller or control actuator to obtain the desired response, while closed loop control systems use feedback signals to generate the output. Common types of industrial control systems include programmable logic controllers (PLCs), distributed control systems, and supervisory control and data acquisition (SCADA) systems [7, 8].

Sensors and actuators are essential components of control systems. Sensors monitor and measure physical aspects of the environment and convert them into electrical signals, while actuators receive electrical signals and produce physical outputs. Common types of industrial automation sensors include proximity sensors, position/velocity sensors, force/pressure sensors, and vibration/acceleration sensors [7, 8].

The primary function of a material handling system is to select the appropriate materials handling equipment and minimize overall costs. The system should also ensure safety, efficiency, and flexibility in material handling operations.

In summary, this literature review provided an overview of the various types of material handling equipment and control systems used in gold recovery processes. It highlighted the importance of selecting the right equipment based on material characteristics and process requirements. The information gathered from this review guided the design of an efficient and effective mechanical activated carbon handling system for gold recovery.

III. METHODOLOGY AND CONCEPT GENERATION

The methodology used for the design of a mechanical activated carbon handling system in gold recovery outlines the steps taken to generate concepts and select the most suitable design concept for the system. This section discusses the advantages and disadvantages of each concept and provides a detailed explanation of the working principles for each design.

Concept generation involved the generation of multiple design concepts for the activated carbon handling system. The aim was to explore different approaches and identify potential solutions for efficient gold recovery.

Concept 1 shown in Figure 1 uses a gantry as the primary mechanism for movement within the plant. In this design, activated carbon falls by gravity onto a vibrating screen and is washed by water from sprinklers. The washed carbon then enters a steel bucket suspended on the gantry, which can be raised or lowered using a semi-automatic chain block. Once the bucket is full, the carbon is directed into the stripping column for further processing. This concept offers low initial costs and energy requirements but requires trained personnel for operation and poses a hazard due to the suspended heavy load.

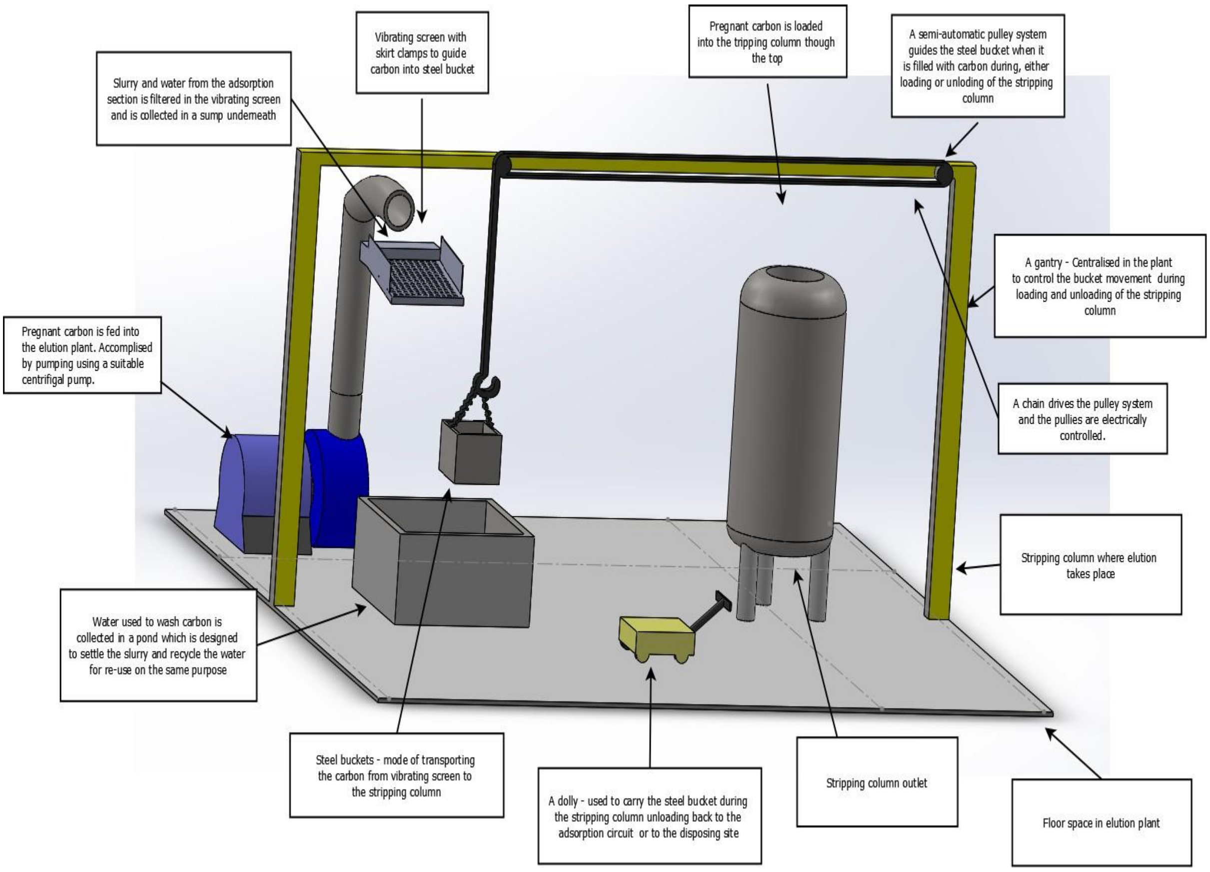

Figure 1: Illustration of the proposed first design concept

Concept 2 incorporates another vessel, a carbon column, in addition to the stripping column. The slurry-covered activated carbon is fed into the carbon column for washing, and then water-slurry gate valves are used to remove the slurry. The carbon is then pumped into the stripping column for elution. After elution, the activated carbon is released onto a conveyor belt, which transports it to the adsorption section or a storage facility. Concept 2 reduces human interference and is time efficient but requires high maintenance for pumps and conveyor belts.

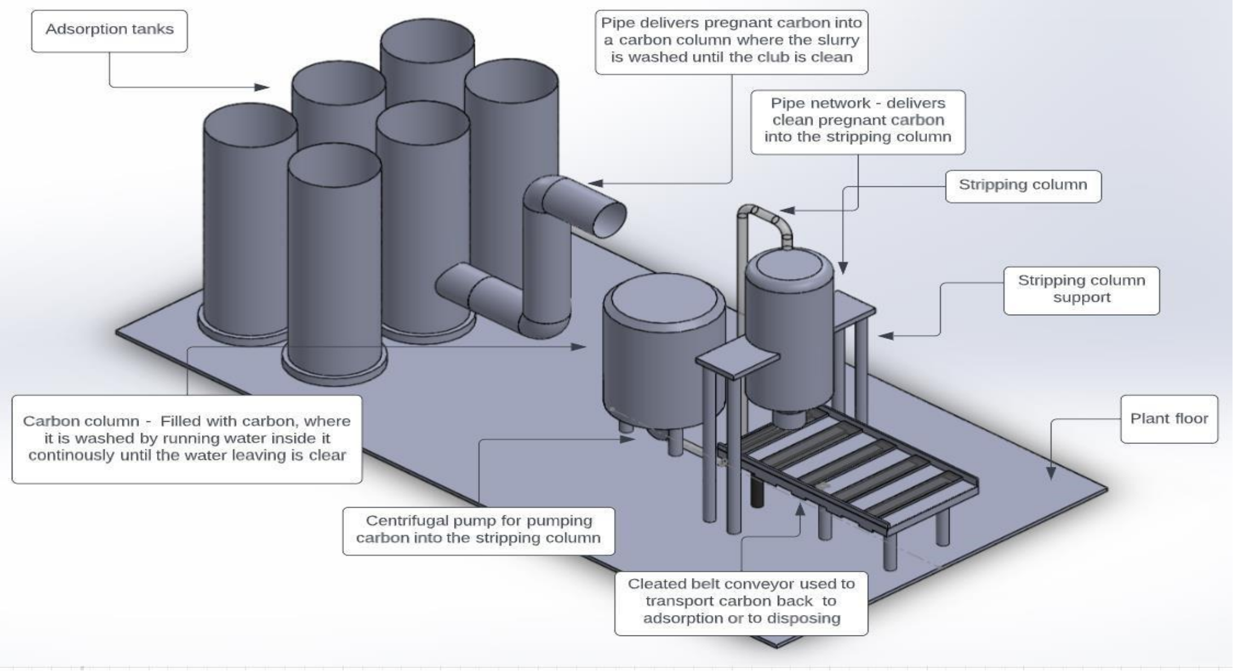

Figure 2: Illustration of the proposed second design concept

Concept 3 involves feeding activated carbon onto a conveyor belt with skirt clamps, which transports it to a vibrating screen for washing. The washed carbon then enters a hopper for controlled feed into the stripping column. After elution, the carbon falls onto another conveyor belt, which deposits it into a steel bucket lifted by a bucket loader. Concept 3 offers relatively easy operation and less human interference but has high initial costs and requires caution due to hazards associated with conveyors.

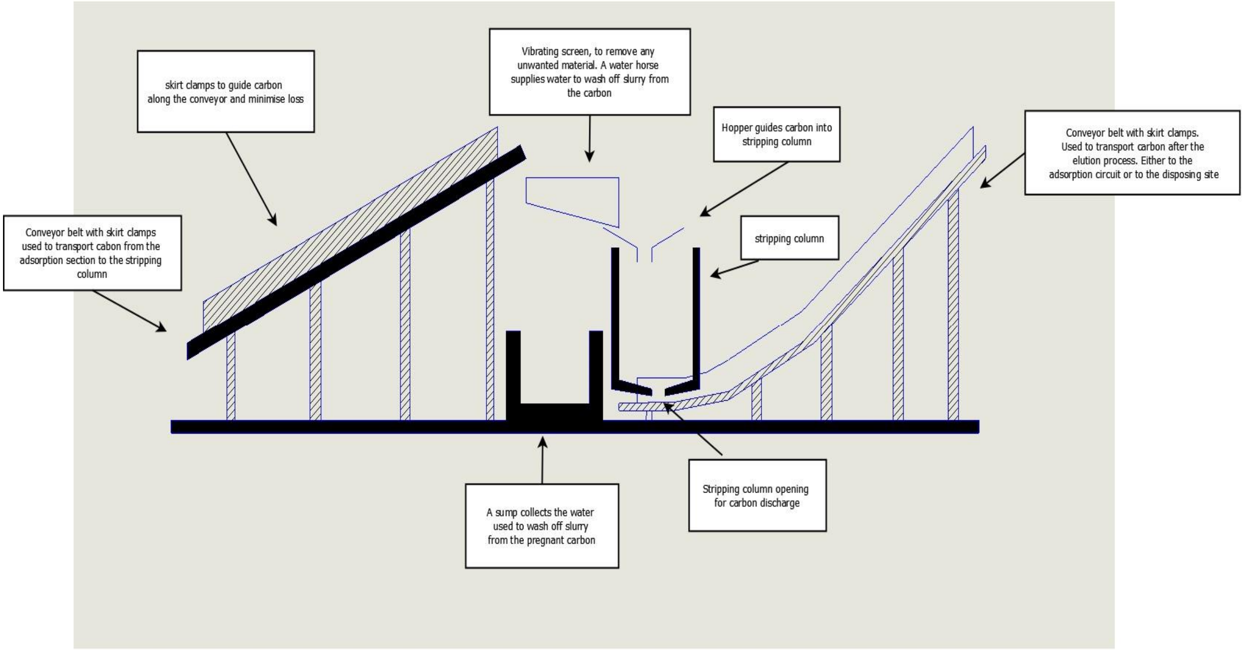

Figure 3: Illustration of the proposed third design concept

Concept Screening is a method developed by Stuart Pugh in the 1980s to narrow down concepts and select the most suitable ones. This process involves using Pugh's matrix and comparing concepts to a reference concept. Table 1 and 2 provide a visual representation of the concept narrowing process.

Table 1: The concept Rating Key for the Screening Process

Concept rating	Explanation
0	Concept **1** is like **4** for the given screening criteria.
+	Concept **1** is better than **4** for the given screening criteria.
-	Concept **1** is worse than **4** for the given screening criteria.

The complete concept screening matrix is shown in Table 2 below which shows that concept 1 and 2 can be combined whilst concept 3 is left behind.

Table 2: Complete Concept Screening Matrix

Selection Criteria	Concept 4 (Reference)	Concept 1	Concept 2	Concept 3
Cost 6%				
Assembly cost	0	+	-	-
Time of Assembly	0	0	-	-
Ease of Assembly	0	+	+	0
Ease of repair	0	+	-	-
Machine use cost	0	0	0	0
Payback time	0	-	-	-
complexity	0	+	+	-
Competitive advantage	0	+	+	+

Efficiency 40.5%				
Overall system availability	0	+	+	+
Comply with purpose	0	-	-	-
Production time: volume eluted per hr.	0	+	-	+
Overall system reliability	0	+	0	0
Ease of system maintenance	0	+	-	-
Parts availability	0	+	-	-
Total system weight	0	0	-	-
Durability 24.5%				
Strength of system	0	+	0	0
Durability of system	0	+	+	+
Health 15%				
Environmental concern	0	0	+	-
Safety of machine use	0	-	+	-
Market 9.9%				
Size	0	+	0	0
Durability	0	+	+	0
Maturity	0	-	+	0
Competition	0	0	0	0
Portability 3.8%				
Ease of use	0	+	0	+
Ease of transportation	0	-	+	+
System size	0	-	+	0
Sum 0s	26	5	6	8
Sum – s	0	6	8	11
Sum +s	0	14	7	5
Net score	**0**	**8**	**3**	**-6**
Ranking	**3**	**1**	**2**	**4**
Continue	**No**	**Combine**	**Combine**	**No**

Table 3 presents the Rating for Concept Scoring Criterion. The rating scores range from 1 to 5, with 1 indicating that a concept is much worse than the reference, and 5 indicating that a concept is much better. This scoring system allows for more refined comparisons based on each criterion.

Table 3: Rating for Concept Scoring Criterion

Rating Score	Relative Performance
1	Much worse than reference
2	Worse than reference
3	Same as reference
4	Better than reference
5	Much better than reference

Table 4 provides a comprehensive concept scoring table validating that concept 1 and 2 can be further developed.

Table 4: Concept Scoring Matrix

Selection criteria	% weight	Concepts				
		Concept 4 - Reference		**Concept 1&2**		
		rating	**Weighted score**	**rating**	**Weighted score**	
Cost						**6%**
Production cost	0.5	3	0.015	4	0.020	
Duration of process	0.5	3	0.015	4	0.020	
Ease of process	0.5	3	0.015	4	0.020	
Ease of repair	0.5	3	0.015	3	0.015	
Machine use cost	1.5	3	0.045	3	0.045	
Payback time	1,5	3	0.045	4	0.060	
complexity	0.5	3	0.015	3	0.015	
Competitive advantage	0.5	3	0.015	4	0.015	
Sub total			**0.18**		**0.225**	
Efficiency						**40.5%**
System availability	5	3	0.150	4	0.200	
Comply with purpose	6	3	0.180	4	0.240	
Appearance of system	7	3	0.210	4	0.280	
Production time: tons eluted per hr.	6.5	3	0.195	5	0.325	
Overall system reliability	1	3	0.030	5	0.050	
Ease of system maintenance	5	3	0.150	4	0.20	
Parts availability	5	3	0.150	3	0.15	
System weight	5	3	0.150	3	0.15	
Sub total			**1.215**		**1.595**	
Durability						**24.5%**
Strength of system	6.4	3	0.192	4	0.256	
Durability of process	8	3	0.240	5	0.400	
Sub total			**0.432**		**0.656**	

Health						**15%**
Environmental concern	5	3	0.150	4	0.20	
Safety of end product	5	3	0.150	5	0.25	
Safety of machine use	5	3	0.150	4	0.20	
Sub total			**0.450**		**0.650**	
Market						**9.9%**
Size	4	3	0.120	3	0.120	
Durability	4	3	0.120	3	0.120	
Maturity	0.5	3	0.015	3	0.015	
Competition	1.4	3	0.042	4	0.056	
Sub total			**0.297**		**0.311**	
Portability						**3.8%**
Ease of use	1.2	3	0.036	4	0.048	
Ease of transportation	1.8	3	0.054	5	0.090	
Machine size	0.8	3	0.024	4	0.320	
Sub total			**0.114**		**0.458**	
Total score	**100%**		**2.688**		**3.895**	
Continue			**No**		**Yes Develop**	

The product decomposition shown in Figure 4 was used to break down the final chosen concept into its physical elements, providing a complete description of the product. This approach allows for a detailed understanding of the system and identification of potential design challenges.

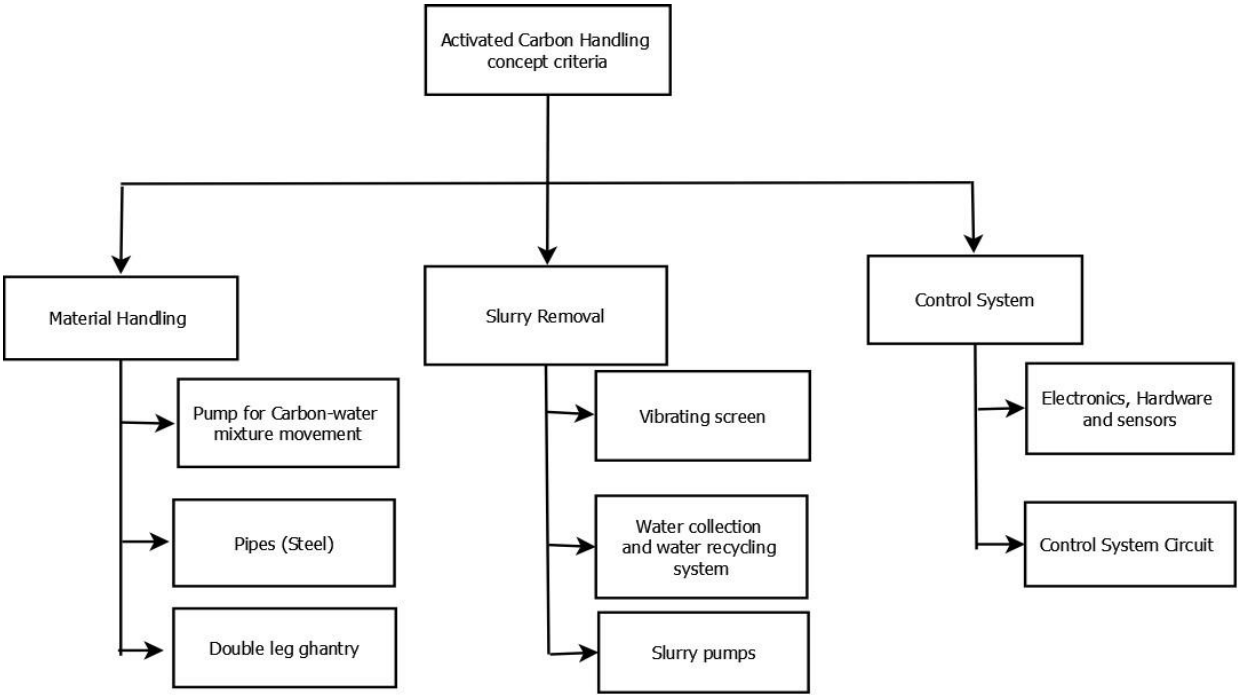

Figure 4: Structural Decomposition of the chosen design concept

IV. DETAILED DESIGN

The detail design involved calculations to determine the size of materials and components. These calculations were used to determine the specifications for the materials and components that will be used in the project.

Process Flow Calculations: The first step in the design process was to determine the rate and volume of materials and fluids that will be used in the mechanical material handling system of an elution plant. These calculations are important to ensure that the materials and fluids are flowing through the system at the appropriate flow rates, pressure, and velocity. If the flow rate is too high or too low, it can lead to inefficiencies or damage to the system.

Volume of Activated Carbon: To determine the volume of activated carbon that will be processed, we considered the production requirements. In this case, XYZ Mines on average produces a minimum of 40 kg of gold each month. To meet this requirement, 3500 kg of activated carbon should be eluted each day. This volume of activated carbon set the basis for all subsequent calculations and served as a reference for the flow rates in the system.

Flow Rate of Water and Eluent: Water is used to wash off slurry from the carbon column, while a solution (eluent) is used to desorb the gold from the activated carbon in the stripping column. The volumes of water and eluent needed depend on the production requirements, the concentration of gold in the eluent, and the mass balance calculations for the system. Based on these calculations, an estimated gold concentration of 20 parts per million (ppm) was used.

Cross-sectional Area of the Pipes: To calculate the cross-sectional area of the pipes, we assumed a velocity of 2 meters per second for both the eluent and water flow. This assumption allowed us to determine the appropriate diameter of the pipes. We calculated the diameter using the flow rate and velocity of the fluid, and then selected the closest standard pipe size that satisfied the calculated diameter.

Pipe Length and Pressure Drop Across the Stripping Column: The required pipe length was determined by the distances within the layout of the plant. In this case, the total pipe length required is 6 meters for both the stripping column and the carbon column, including any bends or elbows. As fluid enters the stripping column from the top and exits through an outlet at the bottom, there is a pressure drop that occurs within the vessel. This pressure drop needed to be calculated to ensure that the system operates efficiently. The pressure drop is influenced by factors such as the internal diameter of the pipe, the flow rate, fluid viscosity, and internal roughness of the pipe.

Material Stress and Strain: Calculating the maximum stress and strain that a vessel can withstand was important for ensuring the safety and integrity of the system. This calculation involved considering the material properties of the vessel, the operating conditions, and the forces acting on the vessel. In this case, we calculated the maximum stress and strain for the stripping column, which was made of mild steel (ASTMA36) with a tensile strength of 400 MPa.

Power Requirements: Determining the power requirements for the motors driving the pumps in the system was crucial to ensure that the system operates effectively. This calculation involved considering the flow rate, volume of the mixture, lift, and efficiency of the pumps. By calculating the power requirements, determined the voltage, current, and energy consumption for the system.

Total Energy Consumption for the Whole System: To determine the total energy consumption for the whole system, we multiply the power requirements by the operating time of the system. In this case, since the elution plant operates around the clock (24 hours a day), we multiply the power requirements by 24 to obtain the total energy consumption in kilowatt-hours (kWh).

Heat Transfer Calculations: Understanding the heat generated during elution and the heat transfer coefficients was essential for designing an efficient activated carbon handling system. These calculations involved considering the temperatures generated during elution, the heat coefficient for the elution column, and the heat dissipated by the cooling system. By calculating these parameters, we optimized the system's efficiency and performance.

Conveyor Belt Calculations: Calculating the parameters for the conveyor belt was necessary to ensure the proper transportation of activated carbon grains. This calculation involved determining the belt speed, belt tension, motor power, roller spacing, belt width, and belt length. These parameters ensure efficient and reliable transportation of the activated carbon grains within the system.

Gantry Calculations: The gantry provides a supporting platform for transferring activated carbon to the regeneration plant or for disposal. This calculation involved determining the weight requirements, including the weight of the gantry.

V. RESULTS AND DISCUSSION

This section provides a comprehensive overview of the calculations and analyses conducted during the design process of a mechanical activated carbon handling system for gold recovery.

In Table , process flow calculations were performed using fluid mechanics and heat transfer principles. The calculations included are of activated carbon, flow rates of water and eluent, and pressure drops. These calculations ensured that the design specifications were met, optimizing energy consumption and costs.

Table 5: Process flow results

Parameter	Value	Units
Flow rate, Q	0.0075	m^3s^{-1}
Area, A	0.00375	m^2
Diameter, D	3	In.
Friction Factor, f	0.1532	-
Pressure drops, ⍰P	3.65	Pa

Material stress and strain analysis, summerzied in Table 6, relied on solid mechanics and finite element analysis. Properties of materials such as steel, rubber, and plastic were characterized, and stress and strain distribution in components (tanks, pipes, valves) were calculated. The analysis confirmed that the materials met the necessary strength, durability, and corrosion resistance criteria.

Table 6: Results for material stress and strain

Parameter	Value	Units
Hoop Stress	2	Mpa
Longitudinal Stress	1	Mpa
Von Mises Stress	2.65	MPa
Strain	0.000132	
Deformation	0.0264	mm

Power requirements and heat transfer calculations, outlined in Table 7, utilized thermodynamics and heat transfer principles. Energy balance equations were used to calculate power requirements, considering pump, fan, and motor efficiencies. Heat transfer calculations helped predict temperature distribution, aiding in thermal stability, material selection, and process optimization.

Table 7: Summary of System Power Requirements and heat requirements

Parameter	Value	Units
Power (Carbon column motor)	1.7	KW
Power (Stripping column motor)	24.73	KW
Current (Carbon column motor)	7.08	A
Current (Stripping column motor)	103.04	A
Total Energy consumption	634.32	KWh
Specific Heat Capacity, Q	395.16	KJ
Area	2.42	m2

Overall Heat Transfer component	0.49	-
Overall Heat dissipated	1.03	KW

Conveyor belt calculations, detailed in Table 8, relied on mechanics and material science. Calculations involved belt tension, power requirements, and material strength. The calculations indicated that the system would function effectively, except for the conveyor belt motor, which had a high current requirement. Solutions for this issue were discussed in subsequent chapters.

Table 8: A summary of conveyor belt calculations

Parameter	Value	Units
Belt Speed, v	0.041	ms-1
Effective tension	846.91	N
Slack side tension	-520.02	N
Tight side tension	2200.93	N
Motor power	11	KW
Belt roller spacing	2	m
Belt width	1.0	m
Belt length	10.2	m

The gantry calculations, presented in Table 9, utilized mechanics and materials technology. The calculations focused on structural integrity and load capacity, ensuring that the gantry could adequately support and distribute loads. The design parameters were optimized to achieve a lightweight and flexible gantry without compromising structural integrity.

Table 9: A summary of gantry calculations

Parameter	Value		Units
Total weight	800		Kg
Force to move load	5395.5		N
Diameter of pulley	0.18		m
Number of groves	4		-

Wire rope and safety factor calculations, discussed in Table 10, used mechanics and material science principles. The calculations involved selecting wire rope diameter, strength, and determining safety factors for different loads and scenarios. The design ensured that the wire rope system was durable, resistant to wear and tear, and met safety requirements.

Table 10: Summary for wire rope calculations

Parameter	Value	Units
Wire rope diameter	3.1	mm
Length	11.2	m
Clearance	7.1	mm
Safe Working Load	7.85	KN
Safety factor	2.55	-

The Figure 5 and 6 presents detailed working drawings and a prototype photo, showcasing the mechanical components of the activated carbon handling system that were not clearly represented in generated models.

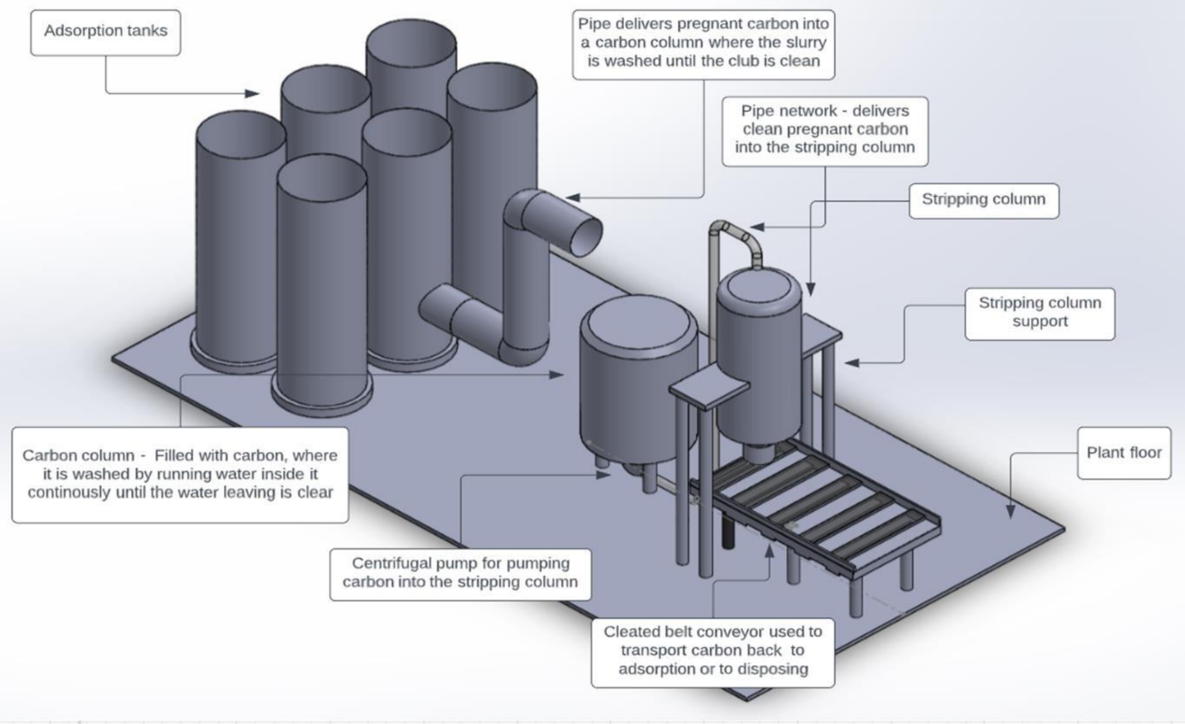

Figure 5: Isometric view of the system layout

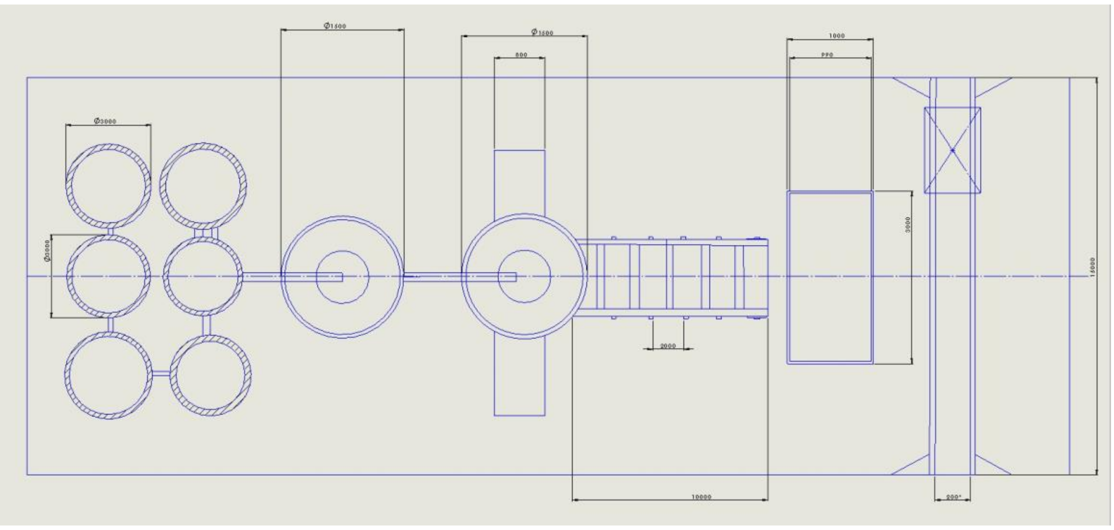

Figure 6: Plan of the system showing dimensions.

A working prototype was fabricated which is shown in Figure 7 below.

Figure 7: Prototype photo

Overall, the analysis and calculations conducted in this section verify the functionality, feasibility, and safety of the mechanical activated carbon handling system for gold recovery.

VI. CONCLUSION

In conclusion, this project focused on the design and development of a mechanical activated carbon handling system for gold recovery at XYZ Mines in Kwekwe, Zimbabwe. The objectives of the project were successfully achieved, addressing key challenges in the gold recovery process.

Objective 1 aimed to design a carbon receiving system. Through the implementation of a conveyor belt and a quality control system, carbon was efficiently transported from the adsorption tanks to the regeneration kiln. Recommendations were made to optimize the motor power calculation and improve the system's frictional losses.

Objective 2 aimed to design a water supply system to replace the horse sprinkler system. The bathing mechanism in the carbon column proved to be more efficient, cost-effective, and safer for employees. The system ensured a continuous flow of clean water, resulting in improved gold recovery rates while reducing water usage.

Objective 3 focused on designing a lifting and stripping column loading and unloading mechanism. Despite design challenges, a mechanism was developed that supported the loading and unloading of the carbon column, reducing time and effort, and enhancing overall process safety.

Objective 4 involved conducting an economic analysis to justify the project's cost. The analysis revealed that the mechanical activated carbon handling system would lead to increased gold recovery yield and operational efficiency, resulting in reduced operational costs and a substantial return on investment.

Objective 5 emphasized the development of a working prototype to demonstrate design functionality. The prototype successfully transported carbon, washed it effectively, and improved overall process efficiency. It proved to be a valuable investment for XYZ Mines, showcasing increased gold recovery yield.

Recommendations for future improvements include periodic maintenance, further research, and development for optimization, testing the system under various conditions, and designing similar systems for other plant layouts. Future work may involve enhancing the control system with real-time monitoring and reporting, developing computer simulation techniques for predicting system performance, and incorporating an in-house wastewater recycling plant. In summary, this project has provided a comprehensive and informative guide for the design and implementation of a mechanical activated carbon handling system in gold recovery. Its successful outcomes have the potential to significantly improve the efficiency and profitability of the gold recovery process at XYZ Mines.

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