UNIVERSITY OF MANITOBA

Department of Mechanical Engineering

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Starter Strip Nickel Removal Process Design

Final Design Report

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EXECUTIVE SUMMARY

A new system design for removing leftover nickel from the refining process was required by Vale at their Thompson, MB facility. After the refining process, some nickel remains on plastic starter strips and must be removed so that the strips may be reused and the nickel is recovered. The current removal system involves an employee manually removing the nickel by hitting the starter strips against a hard surface, which is labour intensive, unsafe and time consuming. The client required a design that required less manual labour by the employee, was safer, and improved through-put of the cleaned starter strips.

The final design selection was made by first collecting a broad range of initial concepts and ideas, which were later refined into preliminary designs. These designs were then screened for feasibility through scoring schemes which evaluated their expected performance against the requirements and constraints of the design problem. The five highest scoring designs were further researched, and the final tilted tumbler design was selected.

The tilted tumbler design consists of a rotary tumbler mechanism made up of two five foot long concentric drums, with a major diameter of five feet open at both ends. The diameter of the inner drum will contain the starter strips and nickel and is intended to clean approximately 500 strips per batch, with each batch intended to tumble for 30 minutes. Based on an eight hour workday, this will allow approximately 8000 strips to be cleaned per day which is a 60% increase to the through-put of the current system, approximately 5000. At the end of the 30 minute tumble cycle, the strips will remain in the inner barrel, and the removed nickel will have fallen into the outer barrel through holes in the inner barrel. The constraints of the working environment ban the use of galvanized steel or aluminum; therefore the tumbler system will be made from 316 stainless steel. The door on the unload end of the tumbler will have two separate access hatches that can be opened to allow separate unloading of the nickel and starter strips. The strips for cleaning enter the inlet end of the tumbler via an entry chute. The only employee labour required with this design will be to load and unload each batch which

will take approximately three and a half hours. The estimated cost for the design is $91,243 and the operating costs per year are $82,080 which is within the budget dictated by the three year payback period. Implementing the Tilted Tumbler System will also produce savings of $105,200 per year.

1 INTRODUCTION

Vale is a Brazil-based mining company with operations in countries around the world. They are the second largest producer of nickel in the world. The Vale operations in Thompson, Manitoba are focussed on producing nickel. Their fully integrated facilities include a mill, smelter and refinery. The design work that will be completed for the purpose of this project applies to the refinery. Specifically, it involves designing a system to recover nickel from plastic starter strips in a manner which is safer and less labour intensive than the current practice. The project has been divided into three phases which are defining the problem, initial concept design, and final design details, which is the focus of this report.

1.1 PROJECT STAKEHOLDERS AND ROLES

By identifying the key stakeholders in the project, we are able to make all those invested in this project are being considered, and that their needs are being met or their expertise is being utilized. The main persons who have an interest and are involved in this project are the project sponsor contacts, the project advisor, and the design team members. TABLE I lists all the stakeholders and their respective roles.

TABLE I: STAKEHOLDERS AND ROLES

Stakeholder	Role
Hugh McMillan	Client Contact – Supervisor Mechanical Engineering
Milagros Miranda	Client Contact – Supervising Metallurgist
Natassia Beley	Design Team - Project Manager
Sanjida Zaman	Design Team - Secretary
Bellal Ragoub	Design Team - Technical Advisor
Sahil Sharma	Design Team - Designer
Paul Labossiere	Project Advisor

Regular meetings of the design team members assure that all design individuals’ input is considered. At least one meeting per week with the project advisor ensures that the project stays on track and is moving in the right direction. Weekly communication between the design team and Vale contacts maintains a strong working relationship and allows both parties to voice any concerns or inquiries into the project as they are presented.

1.2 PROBLEM DEFINITION

The final designed system must improve on the current process while adhering to the constraints and fulfilling the requirements as defined by the project stakeholders. The needs and requirements were assessed and documented by the design team after discussing with the client and determining the specific problems with the current process. These constraints and needs were quantified where possible to define the metrics. The results of this design process will be outlined and detailed in the following sections of this report and other final deliverables. Possible project risks were defined so that preventative measures could be taken should they have occurred during this process.

1.2.1 CURRENT PROCESS

During the refining process, nickel starter sheets are placed in electrolytic tanks. Starter strips made of LDPE (low density polyethylene) are attached to these nickel sheets (Figure 1) in order to reduce the risk of employees cutting their hands when unloading the sheets from the tanks, and to prevent the nickel sheets from bending. They also act as isolators from the current and help align the nickel sheets with proper spacing.

Figure 1: Starter Strips [1]

After separation of the strips from the nickel product, some nickel remains on the strips (Figure 2). This nickel must be removed so that the strips may be reused in the refining process. The plastic starter strips are critical to the refinery process and production would be stopped or delayed if they were unavailable. The nickel must also be recovered as it currently costs around $9/lb [2]. As the cost of the nickel is relatively high, Vale wants to maximize the profits by recovering the nickel for further processing in the refinery.

Figure 2: Nickel Rounds on Starter Strips [1]

The current process called "whacking sticks" for nickel removal involves an employee physically striking the starter strips against the hard edge of a bin and recovering the nickel that falls into the bin. A process flow diagram showing how the starter strips go from the start of the refinery process, to the end of the removal process for reuse is shown in Figure 3.

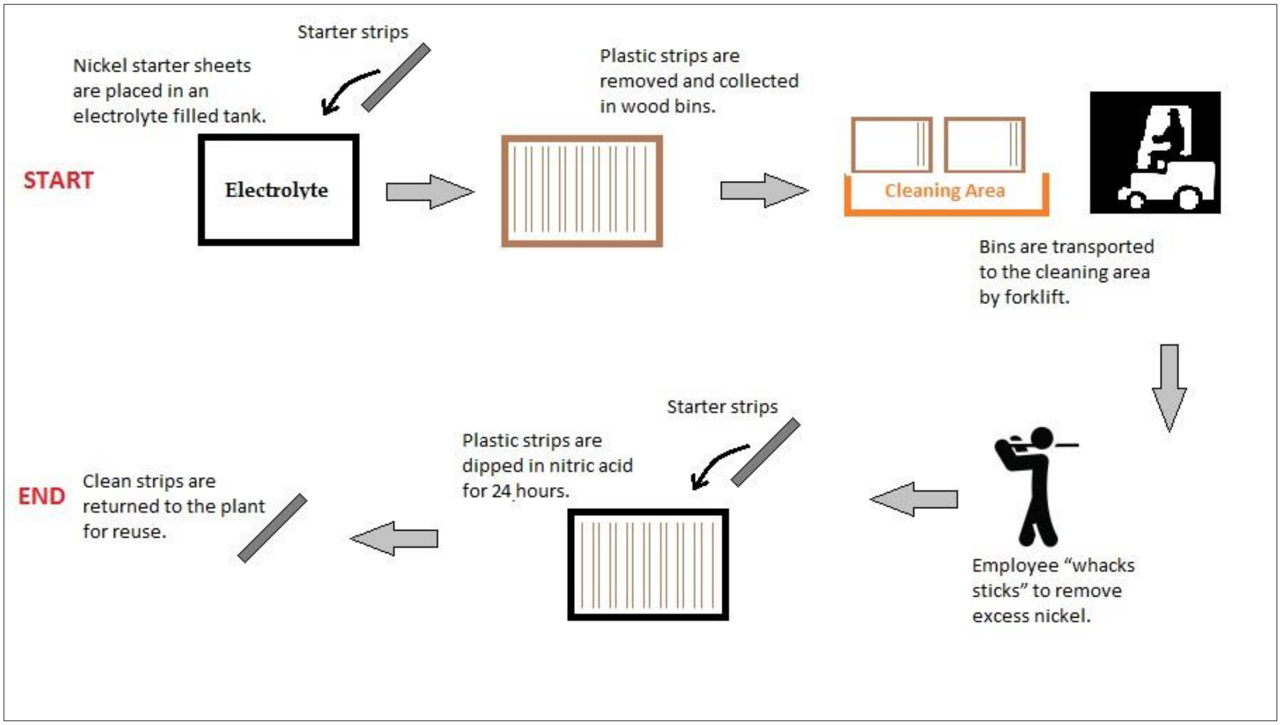


Figure 3: Process Flow [3]

The process shown in Figure 3 needs to be improved for a number of reasons:

- It is labour intensive, requiring one employee to work eight hour days, five days a week.
- It is expensive for the company, as the additional employee effectively costs the company $90/hour.
- It is time consuming.
- It may affect the company's safety target by causing employee injuries either from the physical act of striking the strips, or from airborne shards of nickel.
- The striking of the strips causes cracking and failure, in which case the strips must be disposed of.

The refinery runs 24 hours a day, requiring a continuous supply of starter strips. When the supply of starter strips is low, an employee will be assigned to this "whacking sticks" procedure. In the event that no employees are available for this task, the Operations team must place an order for additional starter strips. The cost of the starter strips is $1.85 for the shorter length and $2.57 for the longer length.

1.1.1 CONSTRAINTS

Design engineers need to consider a multitude of constraints when creating any new component or system. The following sections categorize the constraints specific to this design project into functional, safety, legal, time, and economic constraints.

1.1.1.1 FUNCTIONAL CONSTRAINTS

The functional constraints consist of the space and resources available for the design, size of the starter strips, and material requirements. The area that is currently used for the “whacking sticks” procedure is 15’-10”x17’-6”x10-9” high. There are various obstructions to this space which cannot be relocated. These consist of rails on the wall and ceiling, and a box covering a 575V power supply. The power resources currently in place in the room are two standard electrical power outlets located on the ceiling and wall, the aforementioned high voltage outlet, and a compressed air line rated 85 psi. Also, the steel bins containing the cleaned starter strips after nickel removal must be accessible by forklift, through the open wall area. The allotted space, power resources and access area are shown in Figure 4 below.

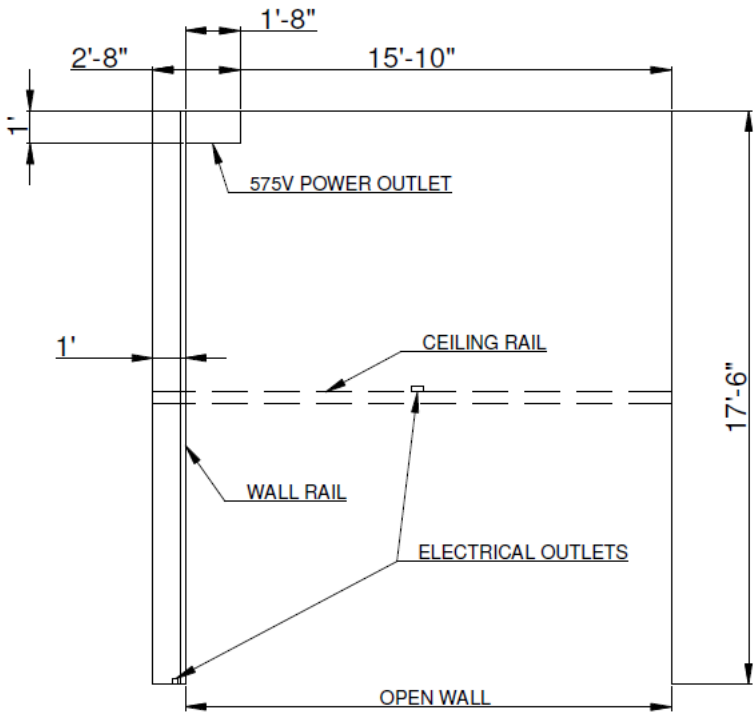


Figure 4: Starter Strip Nickel Removal Area [4]

In terms of material requirements, the design must be made from materials capable of withstanding the highly corrosive environment of the refinery. The current location allotted for the design already has highly corroded areas on the ceiling and floor. As well when chemicals used in the refining process come into contact with aluminum and galvanized steel they produce toxic arsine gases; therefore aluminum and galvanized steel cannot be used at all in the design.

TABLE II summarizes all the functional constraints that will be taken into account for this project.

TABLE II: SUMMARY OF FUNCTIONAL CONSTRAINTS

Functional Constraints	
Size of the starter strips	Accommodate shape of dimensions of the starter strips
	Short: 0.772" x 0.772” x 30LG."
	Long: 0.772" x 0.772” x 45LG."
Space allotted for the design	15’-10” x 17’-6” x 10-9” high
	Obstructions consisting of ceiling and wall rails, voltage
Power Sources Available	575V voltage port
	85psi compressed air

	Two standard electrical outlets
Material Constraints	No galvanized steel
	No aluminum
	High corrosion resistance

1.1.1.2 SAFETY CONSTRAINTS

Compliance to Manitoba workplace health and safety regulations are required by law for industries operating in Manitoba, and therefore it was a major constraint noted by the project sponsor. The specific codes applicable are MR-217, and the sub-sections of interest to this project are machines, overhead electrical lines, a compressed air environment, chemical substances and general electrical safety.

1.1.1.2.1 MACHINES

All machines require safe work procedures and for the workers to be trained on these procedures. All the risks associated with operating the machines must be identified and communicated to the operators. Safeguarding of machines is a crucial part of worker safety. The below listed machine component types require safeguarding as prescribed by MR 217 [5]:

- Any moving parts on the machine
- Energized sources or portions of the machine
- Materials and substances that may be thrown from the machine
- The guarding must be designed and installed with adherence to CSA Standard Z432-04, Safeguarding of Machinery. If guarding not is achievable, alternate procedures are required.

In the case that all the parts of the machinery are not available in clear view to the operator, audible warning systems must be installed to indicate start-up of the machine. To protect the machine operators, emergency stop buttons are required for all conveyors, and safety mechanisms should be put in place to ensure machinery cannot be restarted until an inspection is done. Also, any pressurized hoses installed on the machine must have a restraining device. If a pressurized connection is inadvertently disconnected it might pose a safety risk.

1.1.1.2.2 OVERHEAD ELECTRICAL LINES

Overhead electrical lines need to be considered when they are in a three meter vicinity of the work being performed or where the worker is stationed. When they are within this vicinity, permission must be granted from the electrical authority to commence work. The authority may instruct the employer to hire a second person who will provide signals to the operator and perform a set of tasks to ensure safety of the workers is uncompromised. [5] This will result in increased costs; therefore it is advisable to avoid installation of overhead electrical lines in the vicinity of the worker. Worker training and safe work procedures need to be developed and implemented in the case that overhead electrical lines cannot be avoided.

1.2.1.1.1 COMPRESSED AIR ENVIRONMENT

Prior to work commencement in an environment involving compressed air the regulatory body must be informed of the location and nature of the work and a comprehensive work plan must be put in place. Proper training on safe work and detailed safe work procedures are required. Compliance with CAN/CSA Standard-Z275.3-M86 (R2004), Occupational Safety Code for Construction Work in Compressed Air must be taken into consideration if pressurized air is used in the design. [5]

1.2.1.1.2 CHEMICAL SUBSTANCES

The use of chemical substances in a workplace requires thorough assessment of whether the use of the substance changes the conditions of the workplace. This assessment is done by monitoring effects such as changes in worker’s health and safety, air quality or any findings related to the chemical’s safety. In the case of presence of airborne substances due to the chemicals, a threshold value is established by the American Conference of Government Industrial Hygiene (ACGIH). The concentration of these airborne substances must not exceed the established threshold limits in any case, in order to maintain the safety of the workplace. [5] Ideally the occupational exposure limit to the airborne chemical should be as close to zero as possible. The occupational threshold limit must be lowered from the established threshold hold value (ACGIH), when it poses an added safety risk due to the presence of heat, humidity, pressure and additives. The physical condition of the worker and working duration must also be considered when determining the lowered occupational threshold limit.

1.2.1.1.3 GENERAL ELECTRICAL SAFETY

Energized electrical equipment and lines must be safely guarded and located in order to protect the workers. All electrical equipment such as panels, controlling switches, feeder circuits and branched circuits must be safeguarded from physical damage such as by water or other corrosive materials. Electrical distribution switches must have procedures to be de-energized and locked-out.

1.2.1.2 TIME CONSTRAINTS

The total duration of this project is contained within 83 days, which encompasses the project definition, concept design, and final design phases. As the project sponsor, Vale has its facilities located in Thompson, MB the factor of distance between Thompson and Winnipeg affects our time considerations and communication. In the tight time constraints of this project, our design team realistically only has enough time for one round trip site visit. Because of this, our communication is limited almost exclusively to email and phone contact with the project sponsor.

1.2.1.3 ECONOMIC CONSTRAINTS

The economic constraints include costs related to design team's information retrieval, installation and manufacturing costs. A budget of $1250 was allotted to the team for travel to and from the site. This, in addition to the time constraints has also been a limiting factor in the number of site visits possible by the team. For administrative costs, a $300 budget has been allocated for printing of the reports and other items.

An important constraint mentioned by the client is that the payback period must be less than three years, with an ideal payback period being six months. With this, ideal and maximum allowable costs were estimated for the project. These values were calculated using the effective hourly rate of the employee ($90/hour) multiplied by the number of hours that would be worked in the given amount of time.

.**Maximum Allowable:**

$$90\frac{dollars}{hour}\times 173.33\frac{hours}{month}\times 12\ months\ \times 3\ years = \$561{,}589.20$$

Ideal:

$$90\frac{dollars}{hour}\times 173.33\frac{hours}{month}\times 6\ months = \$93{,}598.20$$

The economic constraints are summarized in TABLE III below.

TABLE III: SUMMARY OF ECONOMIC CONSTRAINTS

Economic Constraints	
Design Team Travel Budget	$1,250
Design Team Administrative Budget	$300
Maximum Design Cost Estimate	$561,589.20

1.2.2 NEEDS

In defining the project, our team brainstormed a list of customer and design needs for the design problem. We further separated these needs into nine main categories. These needs are the criteria we have used to assess how well the final design performs against the current system. As different needs have different levels of importance in the design, we also assigned weightings to the main criteria. The main criteria categories are numbered in

TABLE IV. The sub-needs of each category are listed below these main items.

TABLE IV: CUSTOMER AND DESIGN NEEDS

Needs And Sub-Needs
1. The design needs to be easy to operate.
Be less labour intensive than current practice "whacking sticks.”
Be able to run continuously.
Have a good process flow.
Be ergonomic.
Be easy to turn it on.
2. The design needs to be cost efficient.
Reduce production delays
Be as cheap as possible.
Maintain the integrity of the starter strips.
Have low energy consumption.
Be maintained easily.
3. The design needs to manage the incoming workflow in a time-effective manner.
Run for 24 hours since the nickel production runs for 24 hours.

Be fast enough to accommodate the specification of the rate of production of nickel sheets
Ease the transportation of the starter strips before and after they are cleaned.
Use less than the current resources.
Use the current power sources.
4. The design needs to recover as much nickel as possible.
Have enough force to remove as much nickel as possible from the nickel starter sheets.
Remove different sizes of nickel.
Remove different shapes of nickel sheets.
Remove the nickel from the edges of the nickel sheet.
5. The design needs to maintain the integrity and original shape of the plastic starter
Apply a force that will not damage the starter strips.
Be slow enough to not damage the starter strips.
Narrow the gap of the starter strips and return it to its original shape.
Minimize any friction or sudden movement during the retrieval process of nickel.
6. The design needs to maintain a safe work environment.
Comply with Manitoba's Workplace Safety and Health Act and associated regulations.
Follow Vale's Safety Standards.
Not be intensive labour.
Have a safe noise level.
Have an emergency shutdown
7. The design needs to be easily controlled.
Be operated by less than a worker.
Be operated with minimal training.
Be easy to start up and shut down.
8. The design needs to follow cellular/lean manufacturing concepts.
Utilize minimum space of plant floor.
Reduce the number of tools, pallets and fixtures.
Have low set up time and production time.
Have easy indications of bottle necks.
Have low waste production.
9. The design needs to be easily maintained on site.
Have a preventive maintenance strategy check sheet.
Have scheduled inspections based on production rate.
Have available inventory on site for its critical parts.
Be maintained by Vale's employees and not external contractors.

The importance of the numbered criteria in the table above was subsequently determined by comparing two criteria at a time and deciding which was most important if the design could only satisfy one criterion, and not the other. We made these decisions by group consensus. After comparing all possible combinations, a count of how many times each criterion was considered most important was divided by the number of total comparisons to get an importance weighting for each. These weightings are shown in TABLE V below, and it can be seen that safety and nickel recovery have been assigned highest importance, with respective weightings of 22% and 19%. As well, no criteria received a weighting of zero, meaning that all of the criteria were chosen as most important at least once, and are therefore all valid in assessing the design.

TABLE V: ORIGINAL CRITERIA WEIGHTING MATRIX

	Criteria	Easy to operate 1	Low cost 2	Time efficient 3	Recover as much nickel as possible 4	Maintain integrity of starter strips 5	Be safe 6	Easy to control 7	Lean cellular manufacturing concepts 8	Easy to maintain 9	
1	**Easy to operate**		2	1	4	5	6	7	8	1	
2	**Low cost**			2	4	5	6	2	2	9	
3	**Time efficient**				4	5	6	3	8	9	
4	**Recover as much nickel as**					4	6	4	4	4	
5	**Maintain integrity of starter**						6	5	5	5	
6	**Be safe**							6	6	6	
7	**Easy to control**								8	9	
8	**Lean cell manufacturing**									9	
9	**Easy to maintain**										Total
	Total Hits	2	4	1	7	6	8	1	3	4	36
	Weightings	0.06	0.11	0.03	0.19	0.17	0.22	0.03	0.08	0.11	1

By using these weighted importance values in later scoring of the initial designs, the final scores for each design will be able to accurately reflect which preliminary designs best satisfy the requirements for the most important criteria.

1.2.3 METRICS

From the complete set of brainstormed customer and design needs, our team has further defined these by assigning metric values shown in TABLE VI. Metrics translate customers' needs into quantifiable expectations for the design. They locate progress and improvements designed to achieve target needs. Some needs such as payback period and number of strips cleaned per day are directly measurable or quantifiable. Other needs, such as ease of installation and maintenance are subjective. Metric values such as the bending and fatigue strength of the starter strips were found from the properties of the LDPE material. Where applicable, we have assigned marginal and ideal values to the metrics.

TABLE VI: IDEAL AND MARGINAL VALUES OF METRICS

Metric #	Description	Marginal	Ideal	Unit
1	Force applied to whack starter strips	N/A	Varied	N
2	Dimensions of the strips	N/A	0.772 x 0.772 x 30 short 0.722 x 0.772 x 45 long	in
3	Number of sticks cleaned per day	1680 short 3360 long	>5040 strips	Strips
4	Dimensions of the space available for the process	N/A	210 x 190 x 129	in
5	Weight of the starter strips	N/A	0.27 short 0.4 long	kg
6	Employee cost	N/A	90	$/hr
7	Current labour cost of starter strips	N/A	0.15	$/strip
8	Cost of the design	561,589	93,598.20	$
9	Material of starter strips	N/A	LDPE	-
10	Ultimate tensile strength[1]	3200	1600	psi
11	Safety (incidents)[2]	N/A	0	Number of incidents
12	Personal Protective Equipment[3]	N/A	Low	subjective
13	Fracture toughness	N/A	0.75	psi/in$^{-1/2}$
14	Setup/installation of equipment	N/A	Low	subjective
15	Low noise levels	70	0	dB

[1] The ultimate tensile strength is the maximum stress that a material can withstand while being stretched or pulled before falling or breaking. For LDPE, the ultimate tensile strength was found to be 3200 psi and the design team will aim to use design a system that exerts a maximum stress of 1600 psi given a safety factor of two.

[2] Safety can be quantified as a metric depending on the number of incidents that may happen due the risks in the design. For this purpose, a failure mode and effects analysis (FMEA) will be completed during the design analysis phase.

[3] Personal protective equipment refers to protective clothing such coveralls, safety glasses, gloves etc. The design team will put an emphasis the amount of protective equipment that will be required. For example, the amount of PPE required will be a direct relation to how safe the system actually is.

16	Maintenance	N/A	Low	subjective
18	Total mass	N/A	Minimum	kg
19	Installation time	N/A	Low	subjective
20	Compressed air availability	N/A	85	psi

1.2.4 DELIVERABLES

The expectation of the client is a report detailing the final designed system. A comprehensive cost analysis will be provided in the report showing the projected payback period. An operator's philosophy is also requested from the client, to outline a standard procedure for operation, and all necessary drawings pertaining to the major design components and overall assembly.

In terms of the project overall, the other deliverables expected for this course are all the above mentioned items included in the final report, as well as a poster highlighting the final design, a final presentation and oral defense of the finished design.

1.3 RISK ASSESSMENT

Risks are present in every project and can be best avoided or dealt with if they are initially identified and properly managed. Risks can be categorized into four groups: technical, external, organization and project management.

Technical risks refer to the project requirements, the technology, the complexity and interfaces, performances of the design and the quality. External risks are related to any issues that may arise from subcontractors, suppliers, regulatory bodies, the market and the customer. As for the organizational risks, it includes aspects of project dependencies, resources, funding and prioritization. Finally, project management raises the topic of risks related to estimating, planning, controlling and communication.

The risks for each category is separated and summarized in TABLE VII. All the risks are explained and the preventative measures that should be taken are specified.

TABLE VII: PROJECT RISKS

Technical Risks			
#	Risk	Explanation	Preventative Measures
1	Impact on daily operations	At this moment, there is no current procedure for the "whacking sticks" process. However, when a design is implemented into operations, it will affect many stakeholders. For instance, current employees and training for new system.	→ Standard procedure for design: operators' philosophy[4]
2	Project leadership unaware of project requirements	The project manager is unaware of the objectives, needs and metrics of the project.	→ Secretary to ensure that all information is relayed to the project leader
3	Pros and cons of the project unidentified	The benefits and the disadvantages of the project must be identified at the start of the project. This step can be seen as a "management of change" step. It ensures that all stakeholders impacted by this change are fully aware of the	→ Management of change documented → Revise pros and cons throughout the course of the project

[4] The operators' philosophy is a document with a standardized procedure for the employee to follow in order to operate the system.

#	Risk	Explanation	Preventative Measures
		modifications made to the current process, and that this does not cause losses.	
Project Organization Risks			
#	Risk	Explanation	Preventative Measures
4	Appointed unqualified project manager	This project may not have a qualified project manager due to lack of experience, knowledge, etc.	→ Acquire more hands-on knowledge on Project Management
5	Lack of time from stakeholders	It is important for the project's success that the stakeholders have sufficient time for the project. The stakeholders may have additional responsibilities, but proper communication is key to success.	→ Set internal deadlines → Emphasis on time-management → Communication
6	Scope of the project insufficient	The scope of the project must be clearly identified during the project definition phase.	→ Charter approved by client
7	Communication/ Location	The client is based in Thompson, MB. The design team is located in Winnipeg. Since the facilities are located 8 hours away, it would be difficult to reach the company sponsors in the event a visit is needed.	→ Set up weekly update meetings → Determine preferred method of communication
External Risks			
#	Risk	Explanation	Preventative Measures
8	Measuring the progress of the project	It is difficult to measure the progress of any project. Therefore, quantifiable measures need be implemented.	→ Setting up key performance indicators, common goals of the project
9	Stakeholders on board with all requirements of the project	All stakeholders need to fully aware of the clients' requirements.	→ Approval of project charter
10	Understanding the requirements of the project (Prioritization)	If the requirements are prioritized from the start, it is easier to make decisions for the design considerations.	→ Identify needs → Identify matrix → Develop house of quality
11	Use of existing technology	There is less risk to work with known technology.	→ Benchmarking on the house of quality → Complete external research on processes, designs, systems, patents, etc.

12	Payback schedule higher than 3 years	The payback schedule needs to be less than three years (as it is a requirement).	→ Consistent monitoring of the costs associated to the design → Include all costs (even minor costs)
Planning Risks			
#	Risk	Explanation	Preventative Measures
13	Plan to include time and cost estimates	The project needs to include a sufficiently long grace period otherwise; this may add risk to the project.	→ Gantt chart updated regularly → Include grace period → Project charter approval → Estimating and scheduling completed regularly → Well defined work breakdown structure
14	Inappropriate design screening process	Since there will be a large of number of designs developed, we need to ensure that all possible brainstorming concepts are covered.	→ Brainstorming session → TRIZ analysis → Individual scoring of designs
15	Inadequately identified constraints and assumptions	The project needs to have all constraints and assumptions identified otherwise; designs created may not be implemented.	→ Communication with stakeholders → Codes and Standards reviews → Physical visit to site for functional constraints definition

Like the project's design needs, the risks mentioned above have varying levels of risk. The risk matrix shown below in TABLE VIII categorizes these risks on their likelihood to occur (unlikely, likely and very likely) and their possible impact on the project (minor, moderate and major). The combination of these two variables (likelihood and impact), allow us to assign a general low, medium, high or extreme factor to each risk. The number values in each cell correspond to the risks given in TABLE VII.

TABLE VIII: RISK MATRIX

Likelihood			
Very likely	**Medium** 11, 13	**High**	**Extreme**
Likely	**Low** 8, 12	**Medium** 4, 5, 14	**High** 7
Unlikely	**Low** 1, 9	**Low** 6, 10	**Medium** 2, 3, 15
	Minor	**Moderate**	**Major**

Impact

The low ranked risks were found to be risks 1, 6, 8, 9, 10 and 12. The medium ranked risks are 2, 3, 4, 5, 11, 13, 14, and 15. Risk 7 was found to be of high risk and it is understandable as the distance between Thompson and Winnipeg affects our communication as it is strictly limited to email and phone contact with the project sponsor.

2 CONCEPT SELECTION

Our final design was the result of analysis of a number of preliminary designs, and systematic selection based on the weighted criteria, feasibility and other factors. Twenty preliminary designs were formed from an initial concept generation phase, and this pool of designs was narrowed to five top designs, which were then refined and optimized for the final design. To come up with the initial concepts and ideas, the design team held an initial brainstorming session. These initial concepts were categorized and used to form the preliminary designs. In addition to brainstorming, we utilized the classical theory for inventive problem solving to ensure we had not missed any major design concepts. We then compared the preliminary designs using concept scoring and screening techniques to determine which designs would best meet the design criteria. The top five scoring designs were then researched in more detail to isolate the best final design.

2.1 DESIGN SCREENING AND SCORING

An initial screening process of the general solution concepts allowed us to eliminate a number of concepts which could not be included in these designs. The concepts that were not selected for further development are explained in Appendix B-1. From the remaining concepts, 20 preliminary designs were created. The description of the designs that were not selected can be found in Appendix B-2. To assess the preliminary twenty designs, we created a concept scoring and screening system that allowed us to rank the designs according to how well they met the design requirements found in Appendix B-3. It also allowed us to compare them to the current "whacking sticks" process to see which designs were improvements over the current process, which were poorer than the current process, and which were about the same as the current process. To ensure the screening process returned meaningful results, we also conducted a sensitivity analysis, where we reassessed the designs after varying criteria weightings and scores. The sensitivity analysis is included in Appendix B-4. Once the screening and sensitivity analysis were finished, we were able to narrow down our selection to the five strongest designs. These top five designs were then assessed so that more detailed analyses and research could be conducted. After further research on these five designs, the final design was selected and refined.

2.1.1 FIRST PLACE DESIGN (DESIGN 2) - MAGNET NICKEL MECHANISM

Design 2 focuses on magnetic property of nickel. The starter strips are placed on the magnetic conveyors and go through two electromagnets that attract the nickel from the strips (Figure 5). After that, the starter strips goes through a declined surface grid to the LDPE strips, while the nickel gets collected in the bin.

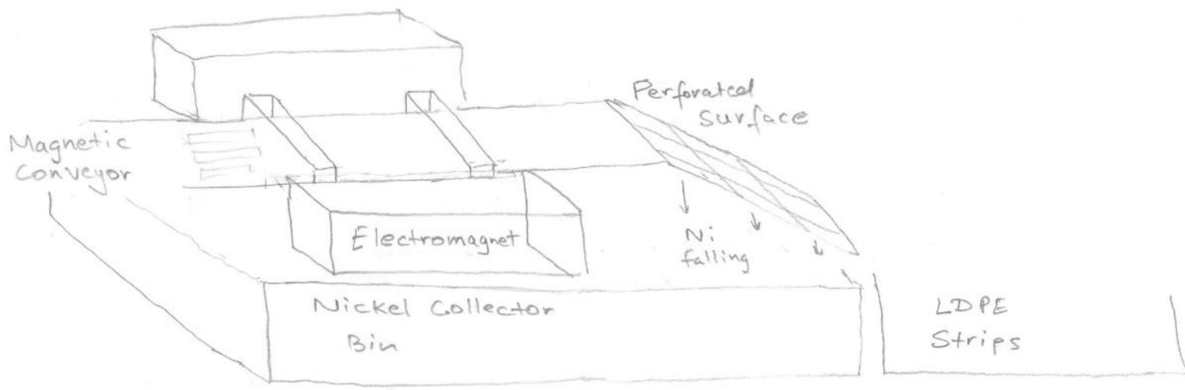


Figure 5: Magnet nickel mechanism sketch.

TABLE IX: DESIGN 2 PROS AND CONS

2.Magnet Nickel Mechanism	
Pros	**Cons**
Stationary - not many moving parts	Smaller quantity in one batch
Using current power sources	Level of efficiency on magnets
Fits within space constraints	Magnets may be expensive as they might require replacement
Lean cell layout	Destructive force for electronics
Minimal amount of automation	Demagnetization of magnets
Easy to manufacture	
Minimal fabrication cost	
Simple design	

2.1.2 SECOND PLACE DESIGN (DESIGN 19) - STRIP WASH

The concept for the "Strip Wash" design is similar to that of a car wash (Figure 6). The starter strips will be placed over a conveyor belt. The first step will be to spray oil/CLR/other fluid on the starter strips. This will allow the plastic and the nickel to lose its connection. Next, a brush with hard bristles will "scrub" the top of the strips and the next set of brushes will be placed on the side of the conveyor belts. At the end of the conveyor belt, a grilled surface will be placed where the nickel will fall off and the strips will be recovered at the end.

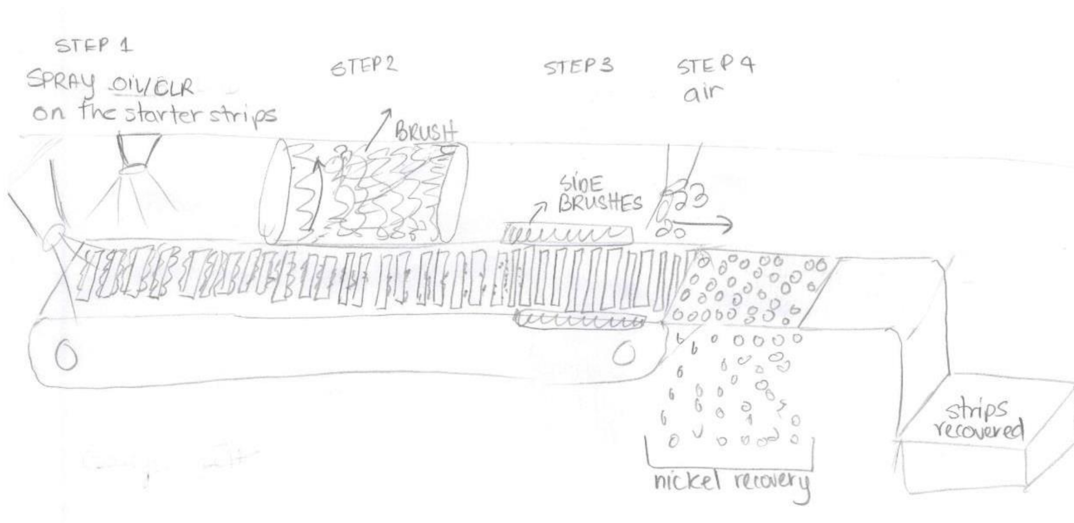


Figure 6: Strip wash sketch.

TABLE X: DESIGN 19 PROS AND CONS

19. Strip Wash	
Pros	**Cons**
High quantity per batch	Combination of complex concepts that reduce reliability of the system
Continuous process	May not fit in the available space
Minimum human interaction	High Cost
Easy to operate	Hazardous with hydraulic and pneumatic pressure

2.1.3 THIRD PLACE DESIGN (DESIGN 3) - EXTRUSION MECHANISM

Design 3 features the extrusion mechanism. The starter strips are placed on the conveyor with divisions separating the starter strips shown in Figure 7. The starter strips go through the extrusion channel that is designed to match the specific dimensions of the strips. The nickel will be removed and fall into the nickel bin through the grid and the LDPE strips will get collected in the “LDPE Strips” bin.

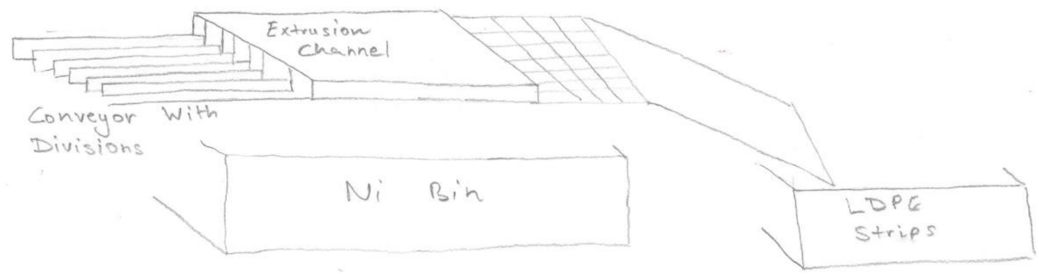


Figure 7: Extrusion mechanism sketch.

TABLE XI : DESIGN 3 PROS AND CONS

3.Extrusion	
Pros	**Cons**
Will recover as much nickel as possible	Smaller number of strips completed per day
Does not affect the shape of the starter strip	Low tolerance in mechanism
Design is easy to operate	Slower process
Inexpensive	Cost efficiency unclear
Easy to repair (as there is only one part)	Would require a human "funnelling system"

2.1.4 FOURTH PLACE DESIGN (DESIGN 6) - ABRASIVE BIN AND MAGNETIC CONVEYOR BELT

This design consists of a vibrating bin full of ceramic abrasives (Figure 8). The whacking sticks with nickel on them are placed in the bin, with the vibrating and abrasive action to loosen and remove the nickel. A magnetic conveyor belt is partially submerged in the vibrating abrasive bin so that the bits of removed nickel will stick to it and be taken up out of the bin, where they will be collected in a separate bin. The cleaned sticks must be removed manually from the abrasive vibrating bin in the current iteration of this design. The conveyor belt does not need to be any specific length. The conveyor simply has to take the nickel out of the vibrating bin and move it somewhere else.

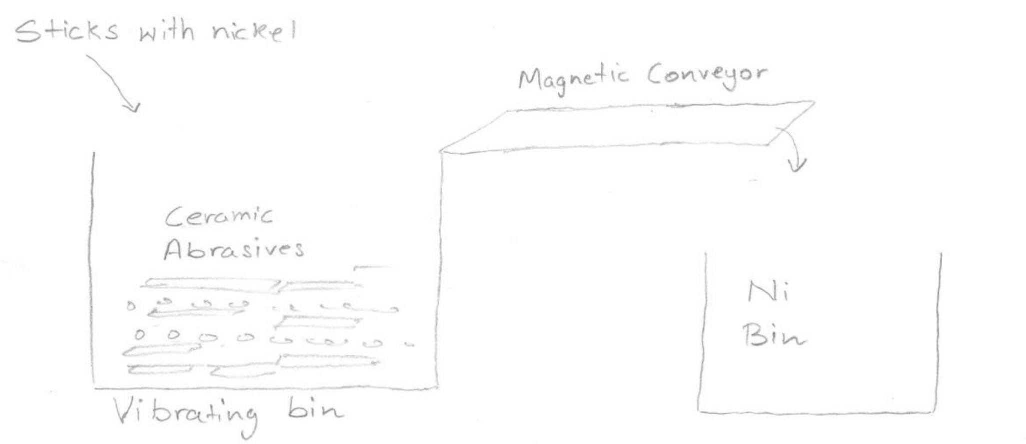


Figure 8: Abrasive bin and magnetic conveyor belt sketch.

TABLE XII: DESIGN 6 PROS AND CONS

6. Abrasive Bin and Magnetic Conveyor Belt	
Pros	**Cons**
Nickel is automatically separated	Must remove sticks manually from abrasives
Relatively inexpensive	Might not collect nickel efficiently
Simple design	Might damage strips
Easy to manufacture	More than one mechanism - decreases reliability
Fits within space constraints	
Lean cell layout	
Possible to integrate current bins	

2.1.5 FIFTH PLACE DESIGN (DESIGN 11) - TILTED TUMBLER SYSTEM

This design consists of a conveyor belt system that passes through a cooling section and at an angle upward (Figure 9). At the highest point, the conveyor delivers the strips to a tumbler that is tilted down towards the bin at the lower end. As the strips move through the cooling section, the LDPE should contract and make it easier to remove the nickel from them. The nickel removal happens as the sticks pass through the rotating tumbler, which also delivers them down to the end bin. Sticks have to be manually removed from the bin to separate them from the nickel in the current iteration of this design.

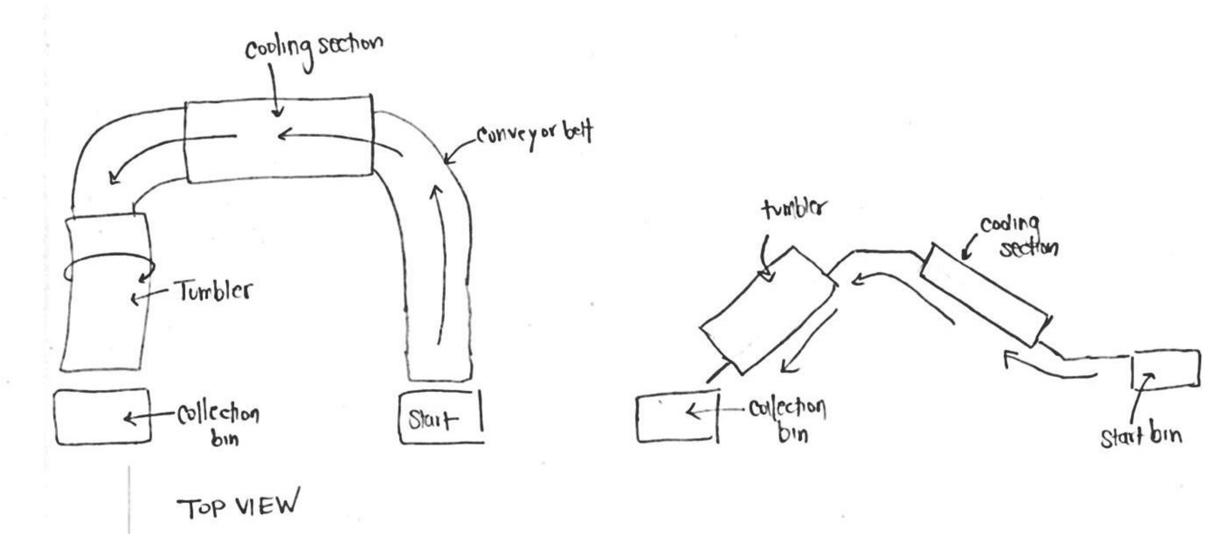


Figure 9: Tilted tumbler system sketch.

TABLE XIII: DESIGN 11 PROS AND CONS

11. Tilted Tumbler System	
Pros	**Cons**
High quantity per batch	Combination of complex concepts that reduce reliability of the system
Continuous process	Requires manual activity
Mix two processes into one	
Minimum human interaction	
Uses space efficiently	

2.1.6 CONCEPT SCREENING AND SELECTION

The selection of the top five designs was done by creating a scoring system and matrix to compare each design against the aforementioned weighted criteria. All group members individually ranked each design according to how well they perceived them to satisfy each of the nine main needs. The ranking scale used was as follows:

5 – Performance far exceeds that of current process.

4 – Performance is a slight improvement over the current process.

3 – Performance is about the same as current process.

2 – Performance is slightly worse than that of current process.

1 – Performance is much worse than current process.

With this ranking scheme, the current process was used as our reference point. Any design resulting in an overall weighted score of less than three would therefore be considered inferior to the current process, and any design with a final score greater than three would be a viable option for further analysis. The rankings from each team member were then averaged and put in the master screening matrix shown in TABLE XIV.

The matrix used for individual ranking can be found in Appendix B-3. These averaged scores were multiplied by the weighted score of each criteria and a final score was determined for each design.

TABLE XIV: WEIGHING MATRIX FOR TOP 5 DESIGNS

	Concept Scoring Criteria	Concept Weighting	2 Rating	2 Wt. Score	3 Rating	3 Wt. Score	6 Rating	6 Wt. Score	11 Rank	11 Wt. Score	19 Rank	19 Wt. Score
1	Easy to operate	0.06	4.5	0.25	3.25	0.18	4	0.22	4.25	0.24	4.75	0.26
2	Low cost	0.11	4.5	0.5	3.75	0.42	3.25	0.36	3	0.33	3	0.33
3	Time efficient	0.03	4	0.11	3.5	0.1	4.25	0.12	3.5	0.1	4.5	0.13
4	Recover as much nickel as possible	0.19	4	0.78	4	0.78	4.25	0.83	4	0.78	4.5	0.88
5	Maintain integrity of starter strips	0.17	5	0.83	4.5	0.75	3.5	0.58	4.25	0.71	4.25	0.71
6	Be safe	0.22	5	1.11	5	1.11	5	1.11	4.5	1	4.75	1.06
7	Easy to control	0.03	5	0.14	2.75	0.08	4.5	0.13	4.25	0.12	3.75	0.1
8	Lean cellular manufacturing concepts	0.08	5	0.42	4	0.33	4	0.33	4.5	0.38	4.75	0.4
9	Easy to maintain	0.11	2.75	0.31	2.75	0.31	3.5	0.39	1.75	0.19	3.5	0.39
	Overall Score		4.14		3.74		3.68		3.65		3.86	

Because we scored each design individually and averaged the rankings, there is already a degree of robustness built into the process, due to a greater amount of input. However, to test the validity of this assumption, we conducted a sensitivity analysis. The results acquired from the sensitivity analysis are included in Appendix B-4. The sensitivity analysis tested the robustness of the screening process by varying the values for criteria weighting and individual rankings. Various iterations of the scoring process were employed to observe if there were any significant changes in the final design scores, or placements.

2.1.7 CRITERIA WEIGHTING

The variation of criteria weights was expected to have a comparatively strong effect on the scores, as opposed to variation of individual rankings alone. As mentioned previously, a list of the main design needs was sent to our Vale contact, Hugh McMillan, to have his rankings applied to them. Two of our sensitivity analysis iterations were dependent on these rankings. TABLE XV below shows the needs ranking as scored by the client. The weighting was done following the same method as for TABLE XVI. The cells highlighted in green represent two criteria that were given equal rankings. For the first iteration of the analysis, we gave preference to the criterion we had chosen as more important in our own weighting matrix. For the second iteration of the analysis, we changed the green highlighted cells to give preference to the criterion we had not chosen as important in our own weighting matrix. These we labeled "Client's weightings, version 1" and "Client's weightings, version 2," respectively.

TABLE XV: CRITERIA WEIGHTING AS RANKED BY THE CLIENT, VERSION 1

		Easy to operate	Low cost	Time efficient	Recover as much nickel as possible	Maintain integrity of starter strips	Be safe	Easy to control	Lean cellular manufacturing concepts	Easy to maintain	
	Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
1	**Easy to operate**		2	1	4	5	6	7	8	**1**	
2	**Low cost**			2	4	5	6	**2**	**2**	2	
3	**Time efficient**				4	5	6	7	8	9	
4	**Recover as much nickel as possible**					4	4	4	4	4	
5	**Maintain integrity of starter strips**						**6**	5	5	5	
6	**Be safe**							6	6	6	
7	**Easy to control**								**8**	7	
8	**Lean cellular manufacturing concepts**									8	
9	**Easy to maintain**										
											Total
	Total Hits	2	5	0	8	6	7	3	4	1	36
	Weightings	0.06	0.14	0.00	0.22	0.17	0.19	0.08	0.11	0.03	1

We also performed another criteria weighting iteration based on the original weighting scheme, by randomly choosing a selection of criteria combinations. By choosing the alternative criterion to the one used in the original scoring, we were able to affect the overall weightings, and hence the final design scores. The criteria weight matrix with alternative criterion choices highlighted in green is shown in TABLE XVI below.

TABLE XVI: TEAM'S WEIGHTING WITH ALTERNATE CRITERIA CHOSEN IN HIGHLIGHTED CELLS

	Criteria	1 Easy to operate	2 Low cost	3 Time efficient	4 Recover as much nickel as possible	5 Maintain integrity of starter strips	6 Be safe	7 Easy to control	8 Lean cellular manufacturing concepts	9 Easy to maintain	Total
1	**Easy to operate**		2	**3**	4	5	6	7	**1**	1	
2	**Low cost**			2	**2**	5	**2**	2	2	9	
3	**Time efficient**				4	5	6	**7**	8	9	
4	**Recover as much nickel as possible**					**5**	6	4	4	4	
5	**Maintain integrity of starter strips**						6	**7**	5	5	
6	**Be safe**							6	6	**9**	
7	**Easy to control**								**7**	9	
8	**Lean cellular manufacturing concepts**									**8**	
9	**Easy to maintain**										
	Total Hits	2	6	1	5	6	6	4	2	4	36
	Weightings	0.06	0.17	0.03	0.14	0.17	0.17	0.11	0.06	0.11	1

With this weighting alteration, criterion number six, which was given the most importance in initial scoring done by the team, now has equal weight as two other criteria, and there is effectively no heavily influencing criteria. The highlighted cells were chosen partially at random, with intent on choosing at least one combination from each criterion for alteration.

2.1.8 SCORE ALTERATIONS

In addition to varying the weights of the criteria, we also adjusted a number of the individual scores of designs. Because we had already integrated robustness in the design by averaging a large pool of scores, we did not expect to see a significant change in final scores. Therefore we utilized a number of different score reassessment schemes, and in some iterations they are combined with the altered criteria weightings. Table XVII summarizes the results of each iteration of the sensitivity analysis. Further description of the iterations is provided after the table.

TABLE XVII: RESULTS OF TOP 5 DESIGNS FOR SENSITIVITY ANALYSIS

Iteration	Top 5 Designs
Base: Original weightings and rankings	2, 19, 3, 6, 11
1. Client's weightings, V1	2, 19, 6, 11, 3
2. Client's weightings, V2	2, 19, 6, 11, 8
3. Original weightings, altered rankings V1	2, 19, 3, 6, 11
4. Original weightings, altered rankings V2	2, 19, 3, 6, 11
5. Altered weightings, altered rankings V2	2, 19, 6, 3, 11
6. Original weightings, altered rankings V3	2, 19, 3, 6, 11
7. Altered rankings of top 2 designs (2 and 19)	19, 2, 6, 3, 11

Base: Original weightings and rankings.

These are the base scoring results of the sensitivity analysis. No weightings or rankings have been changed.

1. Client's weightings, version 1.

The ranking system that was given to the client when we asked him to rank the main criteria was on a scale from 1-5, where 1 was considered to be least important, and 5, very important. With these values, we were able to create another criteria weighting matrix.

However, because the client had ranked them on a scale of 1-5 rather than a strict one criterion or the other basis, we had to make a decision on which was more important for the criteria which had been ranked equally. In this iteration, all criteria which the client had given equal rankings to, we chose the more important criterion to be whichever one we had given preference to in our own criteria weighting scheme.

2. Client's weightings, version 2.

This iteration is the same as iteration 2, however with opposite rankings for the undecided criteria. Instead of giving preference to the needs we had chosen for our own criteria weighting, we used the opposite criterion.

3. Original weightings, altered rankings version 1.

This iteration used the team's original weighting results and instead changed only certain rankings of criteria. One ranking from each design was randomly chosen to be decreased by one. Details on the randomly selected criteria can be found in Appendix B-2 of this report.

4. Original weightings, altered rankings version 2.

This iteration is the same as the previous iteration, but with a different set of random rankings chosen and increased by one instead of decreased. Details on the randomly selected criteria can be found in the Appendix B-2 of this report.

5. Altered weightings, altered rankings (version 2).

This iteration keeps the same set of altered rankings from the previous iteration, however a random selection of items in the criteria matrix has been changed.

6. Original weightings, altered rankings (version 3).

This iteration is a combination of the previous two. Both random sets of rankings were applied at the same time. Original criteria weightings were used.

7. Altered rankings of top 2 designs.

Because the scoring of designs was not done all at once, there may have been different trends in scoring by individual members influenced by their interpretations of the designs at the time, comparison to other available designs and other factors. For instance, the top two designs from the previous iterations had been developed and scored with a period of at least one week between them. In order to ensure the scores were normalized to some extent, we reassessed their rankings as a group, now having comparable amounts of information on each design. The scores for each design did change during the reassessment; however they still remained the top two designs.

The same five designs consistently attained the highest scores, despite changes in the criteria weightings and scoring. From this we can determine that our weighting and scoring system is robust and we can confidently continue our concept selection based on these results. For the full list of design score results from all iterations, please see the sensitivity analysis section in Appendix B-4.

3 FINAL DESIGN SELECTION

The top five designs that attained the highest scores underwent further research with emphasis mainly on feasibility, manufacturability, serviceability and cost. The primary goal of doing further research was to select a final design and develop the components of that system. Once the research is completed, a final concept screening weighing matrix will be developed for the following five designs:

- Strip wash (Design 19)
- Tilted tumbler system (Design 11)
- Extrusion mechanism (Design 3)
- Magnet nickel mechanism (Design 2)
- Abrasive bin and magnetic conveyor belt (Design 6)

3.1 STRIP WASH

The strip wash design ranked second place in the design scoring, based on its perceived performance in ease of operation, time efficiency, and lean cell manufacturing concepts. It was expected to perform as well as or better than the current system in terms of all criteria.

The design consists of a conveyor belt system that transports the starter strips through a line similar to that of an automated car-wash. The strips were to be sprayed with some form of lubricant, such as oil, to help in removal of the nickel. The conveyor belt would move through a series of rotary brushes which would help physically remove the nickel, then they would pass over a grill or mesh type surface where the nickel would be able to drop through to be separated and collected. The major components of interest in this system were the lubricant spraying system, and the rotary brushes mechanism.

To assist in making the final design selection, research was done on rotary brushes and industrial spray systems to determine the feasibility of the strip wash design. We concluded that the rotary brushes may not completely remove the nickel from the strips which is an important need as specified by our client, McMillan.

3.2 TILTED TUMBLER SYSTEM

The tilted tumbler system consistently ranked in fifth place in the concept scoring based on its expected performance in terms of the various aforementioned criteria. Its performance in safety, nickel recovery, and adherence to lean manufacturing concepts were expected to be good, however it scored poorly in terms of ease of maintenance.

The design itself consisted of a U-shaped conveyor system that would transport the starter strips through first, a cooling system intended to cause a small amount of thermal shrinkage of the plastic, then through a rotating tumbler system which would remove the bulk of the nickel. The conveyor belt would also be graded slightly upwards as it transported the strips, so that gravity could aid in the nickel removal as the strips tumbled downwards into the collection bin.

The major components in the Tilted Tumbler system would include a drum which rotates along with drive system that allows it to rotate. Kramer Industries is an American based manufacturer of vibratory, tumbler and abrasive systems was contacted for general benchmarking and cost information on typical products. In terms of benchmarking, the problem specific to this project is quite unique in that it concerns the removal of nickel from plastic, with interest in preserving the plastic strips and recovering the more valuable nickel in any form. For this purpose, a basic dry tumbler unit would accomplish the nickel removal as well as the current process. This manufacturer could supply units made mainly of steel, which would satisfy the material requirements of this project. The size of a unit needed to accommodate the starter strips was estimated to cost $50 000+ [6].

Cooling tunnels are commonly used in and designed for the food industry. Therefore, they are generally made of materials such as stainless steel or plastics for hygienic purposes. This satisfies the basic material requirements of our design that ban the use of aluminum or galvanized steel. However, cooling capability is strongly dependent on the length of the cooling tunnel. As space is very limited in the context of this problem, it is not possible to have a cooling tunnel length greater than 15 feet and tunnels are not readily available at shorter lengths. Also, at such short lengths, appreciable cooling of the starter strips may not be possible.

3.3 EXTRUSION MECHANISM

One of the important aspects of the objective of this project is to design a mechanism that is not labour intensive. For the extrusion mechanism, an employee will need to place the strips on the conveyor belt and ensure it fits within the extrusion channel. This step alone will be extremely time-consuming. The strips will need to be fixed one by one, which is labour intensive and time consuming which would increase the cost of operation of this design.

The tolerance of this design is very low since the strips have to be placed exactly on their designated spot on the conveyor so that the nickel will be removed at the contact of "the extrusion channel". Having a low tolerance will increase the probability of this design to fail or to be inefficient.

Another reason for not selecting this design is that the conveyor will not be able to handle a high number of the strips at once to go through the mechanism. One of the conditions of the new design is to handle at least 5040 strips per day or more since it is the number of the strips being cleaned using the current process and we concluded that each strip will require a minimum of 30 seconds for processing time, which will not be an acceptable timeframe to clean a total of 5040 strips per day.

3.4 MAGNET NICKEL MECHANISM

The concept of the magnet nickel mechanism involves using electricity to separate the nickel from the LDPE strips. To separate the nickel and LDPE, we need to break the adhesive force and one method that may be able to do that is the electrostatic induction. Electrostatic induction uses an object that has astatic electrical charge on its surface to attract the charge of another object. In our case the electrostatic induction will need to induce charges of same sign (negative/negative or positive/positive) so that the nickel will repel from the LDPE strips since electrons of same sign causes a separation between two materials.

The magnet nickel mechanism will require a conveyor belt setup and will need to pass through electromagnets while keeping the plastic strips intact and removing the nickel. One of the setbacks for this design is its small number of strips completed per batch. Also, it is true that the magnet will be able to hold the nickel, however without further testing; we are unaware whether the plastic strips will be separated from the nickel. After contacting a manufacturer, it appears that because the nickel is 99% pure and the size is relatively small, it becomes more difficult to separate as the particle size decreases. The vendor that specializes in these type of applications requires us to send them samples of the nickel and that is unfortunately not possible due to the time constraint of the project.

Moreover, in order to ensure that the nickel is separated from the strips, an extrusion mechanism must be put in place where the plastic strips can move through and the nickel can be collected in another location. That adds another component to the system and adds more complexity to the design.

3.5 ABRASIVE BIN AND MAGNETIC CONVEYOR BELT

This design ranked fourth in the concept screening process. This ranking was based on its effectiveness in terms of safety, removal of nickel and time efficiency. The limitations of this concept that surfaced during the screening process were high cost and difficulty in its operation.

Further research was carried out to determine the feasibility and effectiveness for the nickel removal process. Vibrating conveyor's operating frequencies generally range from 200-3600 vibrations per minute. The amplitude of the vibrations can range from 0.003 in. to 1.5 in. [7]. The higher side of the range applies to heavy equipment which would not comply with our space constraints as shown in Figure 10 below.

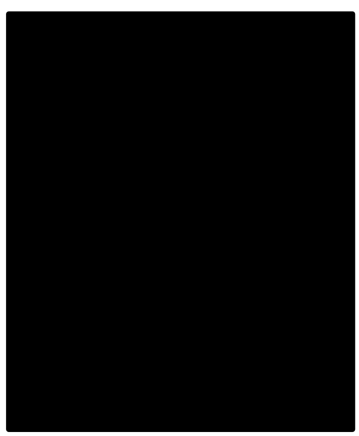


Figure 10: Vibratory shakeout from conveyor dynamics. [8]

A vendor was contacted to get more details and recommendations on how the vibratory bin would work for the application specific to this project. It was learned from the vendor that the lower vibration frequency and amplitude would not be suitable for our application as the vibrating shakeouts are designed to sort bulk materials or separate bulk solids from solid alloys. In this design, solid pieces of nickel are attached to plastic strips which will be difficult to separate.

Apart from the vibration mechanism limitations, vibration of LDPE strips with abrasives may damage the LDPE strips. Using abrasives for surface finishing combined with vibratory motion will act as a filing mechanism on the material, leading to a change in the geometry [6]. The filing of the strips can be reduced by lowering the vibration amplitude and the cycle time of the batch. However, the LDPE strips have varying amounts of nickel stuck to them, therefore an vibration amplitude and cycle time for each batch would be difficult to accurately obtain. In order to maintain the integrity of the LDPE strips, this process would have to compromise on the amounts of nickel removed. Another problem the abrasives pose is that they need to be replaced after a certain number of cycles. This would increase the operating costs as it would require regular ordering and storing of the abrasives.

This concept also requires the strips to be removed manually from the vibrating bin, which would be labor intensive and time consuming. The magnetic conveyor belt would have to be custom designed and fabricated for this process, in order to attract nickel, which has lower levels of magnetism. This would increase the cost further. Based on the batch size required to be processed throughout the day the sizing of the vibrating bin, in combination with the magnetic conveyor this design would have difficulty complying with the space constraints.

3.6 SELECTION OF FINAL DESIGN

Narrowing down our initial twenty design concepts to the top five designs allowed us to complete detailed research and determine the benefits and disadvantages between all five designs. Contrary to conceptual design phase, the final design phase primarily focused on developing the details of one final design. During our meeting for the final design selection, the team reached consensus on developing the tilted tumbler system. The primary factor that drove this decision was the simplicity of the system in comparison to the other four designs.

As well, the tilted tumbler system has a smaller number of components in is less than the other systems. TABLE XVIII summarizes the primary reasons why the designs other than the tilted tumbler system were not selected.

TABLE XVIII: REASONS FOR REMOVAL OF THE TOP RANKED DESIGNS

Design Concept	Reasons for removal
Strip wash	There is a large number of components.
	Maintenance costs are too high as there is an added need for oil.
	Components are not readily available. For example, we would need to develop custom-made brushes.
	During the conceptual design phase, we did not consider how the brushes will remove the nickel from the LDPE strips. There is a high possibility that the mechanism may not work.
Tilted tumbler system	**Selected**
Extrusion mechanism	The tolerance of this design is extremely low as the strips need to come into exact contact of the channel.
	The throughput of the design will be extremely low.
	This design is more labor intensive than the other four designs.
Magnet nickel mechanism	The magnet may not be able to attract all the nickel from the LDPE strips due the nickel being 99.9% pure.
	This design has a small throughput compared to other four designs.
Abrasive bin and magnetic conveyor	The abrasives may damage the LDPE strips.
	This design is excessively labour-intensive and time consuming.
	The maintenance costs are high for this design as the abrasives need to be completely replaced after a certain number of cycles.

4 DETAILS OF THE FINAL DESIGN

The final design was chosen after further analysis of the aforementioned options was the Tilted Tumbler System Design. The design has been refined from the original concept by removing the refrigeration section. The major components of the final design are the inclined tumbler, the drive system and tumbler support. Figure 11 provides a visual representation of the various components of the Tilted Tumbler System.

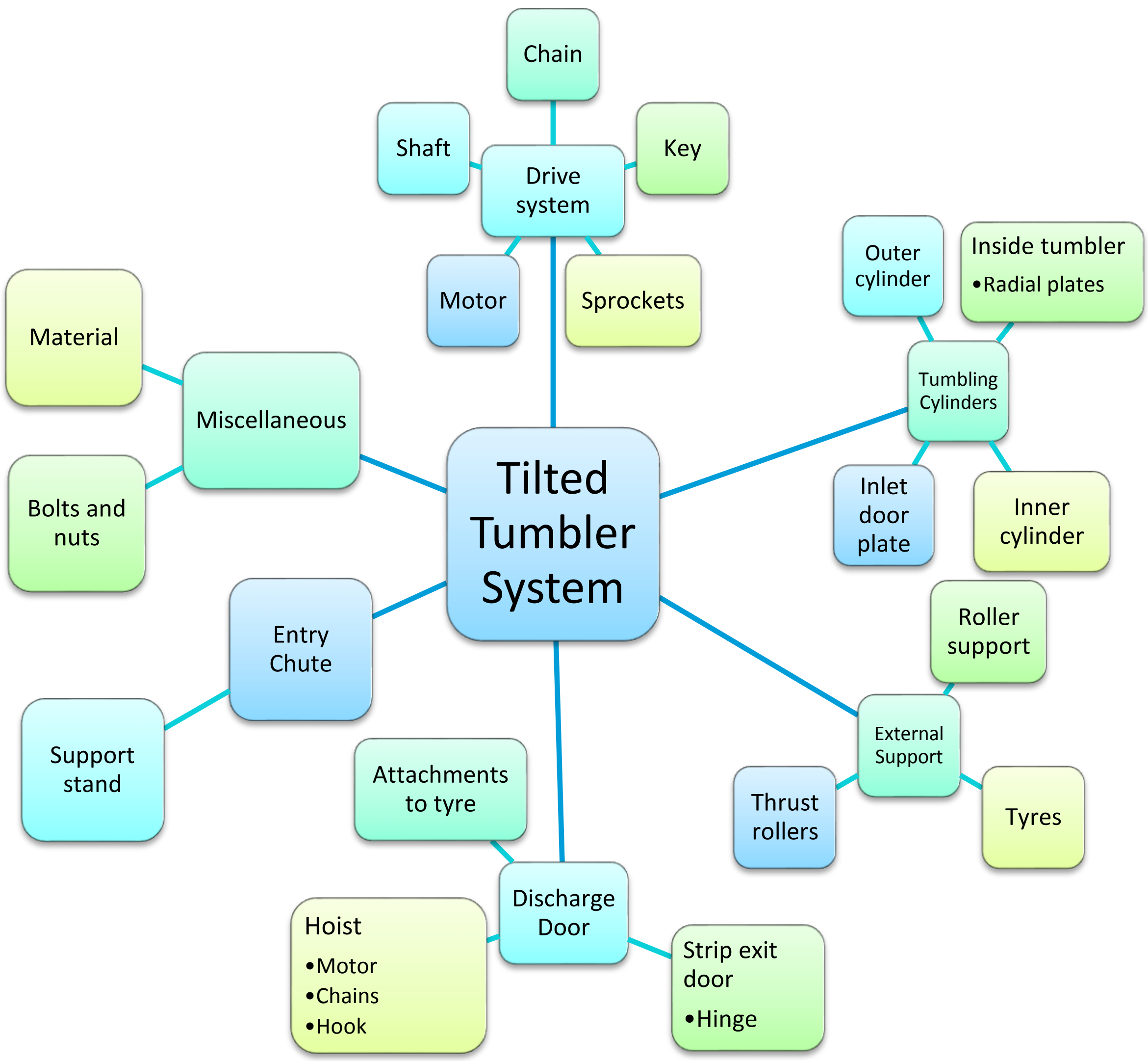


Figure 11: Tilted Tumbler System's major components.

For the most part, we will suggest readily available manufactured products so that they can be easily obtained and installed by the client if they so choose. TABLE XIX categorizes the components that will be designed and purchased. Since the primary component is the drum for our tilted tumbler system we have created a customized design and provided the reasoning and methods for this process.

TABLE XIX: DESIGNED AND PURCHASED COMPONENTS OF THE TILTED TUMBLER SYSTEM

Designed components	Purchased parts
Tumbling cylinders	Transmission system (motor, chain, sprockets, keys and shaft)
Discharge door	Hoist
Entry chute	External support (tyres, roller and thrust rollers)
	Bolts and nuts

As part of our design analysis process for the tumbler drums, we estimated the force exerted on the starter strips in the current “whacking” process, and the force that would cause the strips to fail. For this, we did a separate analysis of the starter strips using analytical, experimental and numerical methods.

4.1 ANALYSIS OF STARTER STRIPS FOR FINAL DESIGN

One of the most important metrics of the nickel removal design is the amount of force necessary to remove the nickel. Analytical, experimental and numerical approaches were used to determine this force. The analytical approach was based on measuring the maximum deflection of the end of the strip during the whacking process and calculating the bending stress from this. The experimental approach involved a rudimentary experiment involving a spring. The numerical approach involved using finite element analysis FEA) software to determine the range of force required to cause the starter strips to crack or fail.

4.1.1 ANALYTICAL METHOD: BENDING STRESS

The analytical method was used to estimate the force acting on the LDPE strip when it is struck against a hard surface. This was a conservative approximation as the strip was assumed to be stationary when the force was applied, whereas in reality the strip is in motion and the hard surface causing a force on the strip is actually stationary. Equation 1 was used and it was assumed that the strip was in pure bending. This means that we assumed no shear forces are present in the strip during the removal process.

The LDPE strip was modelled as a cantilever beam as shown in the Figure 12. In the current nickel removal process, one end is held by the worker (representing the fixed end) and the other end is where the force is applied. Based on visual tests, the LDPE strips can be deflected approximately 30 inches (0.762 m) at the free end if the total length, L, of the strip is 45 inches (1.143 m). This value was considered as the maximum deflection of the strip before permanent deformation would occur.

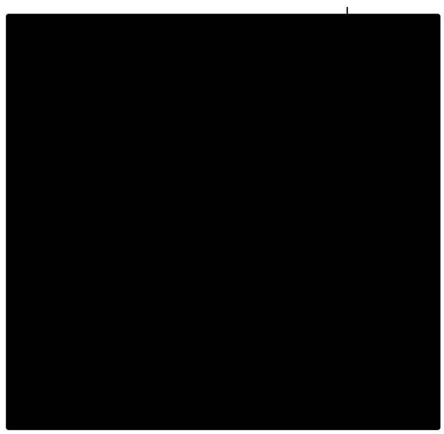


Figure 12: LDPE strip modelled as a cantilever beam [9].

Based on this maximum deflection value, a maximum allowable force, *P*, could be determined from the following equation;

$$\text{Maximum Deflection } (\delta_{max}) = \frac{-PL^3}{3EI}$$

Equation 1: Maximum deflection of a cantilever beam [9].

Where I is the moment of inertia and E is the modulus of elasticity, which is equal to 0.3 GPa for LDPE [10]. The moment of inertia can be computed from the cross-section of the starter strips. The cross-section of the strips is approximately square, with b and h in Equation 2, being equal to 0.772 inches.

$$I = \frac{bh^3}{12} = \frac{0.772^4}{12} = 0.0296\ in^4\ or\ 1.232\ \times 10^{-8}\text{in}^4$$

Equation 2: Moment of inertia of a constant cross-section item [11].

With these values, Equation 1 was rearranged to isolate the force P, which was found to be 1.27lbf (5.65N). This represents the maximum force that can be applied to the strips before permanent deformation would occur. The validity of this analytical method result was tested by comparing it to experimental method results.

4.1.2 EXPERIMENTAL METHOD: SPRING

Due to the elastic nature of a spring, when it is compressed or extended a restoring force resists the deformation of the body. This restoring force is equal and opposite to the force applied to deform the body. An empirical law known as Hooke's Law states that the magnitude of the restoring force, F, is proportional to the deformation of the body, ΔL, as shown by Equation 3.

$$F = -k\Delta \text{L}$$

Equation 3: Hooke's Law [9]

The force and deformation are related by a proportional constant k, corresponding to the stiffness of the body, or spring in this case. Therefore, if the stiffness of a spring is known, the force caused by deflection of the spring can easily be determined.

4.1.2.1 EXPERIMENTAL APPARATUS

The apparatus for the spring force experiment is shown in Figure 13 below. The spring was hung vertically on a hook which was attached to a wooden frame. At the free end of the spring, another hook was attached and this is what was struck by the starter strips to deflect the spring.

Figure 13: Spring experiment apparatus, with spring at rest in its non-deflected state.

Two team members performed this experiment. During our site visit, each team member “whacked” some of the starter strips to remove the nickel; therefore we had a basic idea of the actual force used by the current method. However, this still provided only a rough reference for the striking force in the experiment. Therefore the striking force with which the members hit the strips during the experiment was an approximation of the actual force used in the current method. Also, the strips used in this experiment were clean and without any nickel attached to them and is therefore not a completely accurate representation of the strips in the actual nickel removal process. The experiment was recorded on video so that we could visually estimate the highest deflection of the spring due to the striking force. We repeated the following experiment many times to obtain force values within a consistent range.

4.1.2.2 ANALYSIS

The data gathered from the spring experiment was analysed to estimate the force that is currently applied to remove the nickel from the starter strips. The stiffness constant, k, of the spring was found by attaching an object of known mass, m, to the free end. The force exerted on the spring by the mass was due only to gravity and, after measuring the spring's deflection, ΔL, due to the mass was easily determined using Equation 4.

$$k = \frac{mg}{\Delta L}$$

Equation 4: Determination of stiffness, k, of the spring used in the experiment.

TABLE XX below shows the data used to determine the stiffness of the spring for the experiment in Equation 4. Results are given in both imperial and metric units for convenience.

TABLE XX: PARAMETERS AND RESULTS FOR DETERMINING SPRING CONSTANT, K IN EQUATION 4.

Parameter	Values (imperial)	Values (metric)
Length of the spring prior to loading	16.06 in	
Length of the spring due to impact	16.75 in	
Difference (Δ**L**)	0.687 in	0.0174 m
Mass of body hung from spring (**M**)		1.7 kg
Acceleration due to gravity (**g**)	32.17 ft/s^2	9.81m/s^2
Spring constant (k)		**955.01 N/m**

TABLE XXI shows the deflection and calculated force results for the four trials of the spring experiment.

TABLE XXI: SUMMARY OF EXPERIMENTAL RESULTS FOR EXPERIMENT USING A SPRING.

Trial	ΔL (m)	F (N)
1	0.047	45.30
2	0.101	96.45
3	0.068	64.94
4	0.078	75.40

To keep the estimate of the force conservative, the maximum value was taken from the experiment to represent a worst case scenario of applied force. These experimental results were then compared to numerical results found through finite element analysis.

4.1.3 FINITE ELEMENT ANALYSIS

To estimate the force that would cause the starter strips to crack or fail, we created a 3D model of the 45 inch length starter strip in SolidWorks and used ANSYS to complete a finite element analysis. The simplifying assumptions used in the analysis were as follows:

- The end of the strip held by the labourer in the current nickel removal process is modeled as fixed.
- The force induced by the "whacking" process on the free end of the strip is applied on a section 0.2 inches in length.

Four different forces were applied to the strip 18 N, 15 N, 10 N and 5 N. We computed the maximum stress each strip incurs when these different forces are applied and compared it to the yield strength (12 MPa) of LDPE [12]. In other words, we analyzed this part numerically to determine what force is required to break the strips.

Figure 14 shows the factor of safety of the starter strip when an 18 N force was applied. The orange section of the strip represents the area where the starter strip would fail, the green and blue regions show where the stress in the strip is below the yield stress.

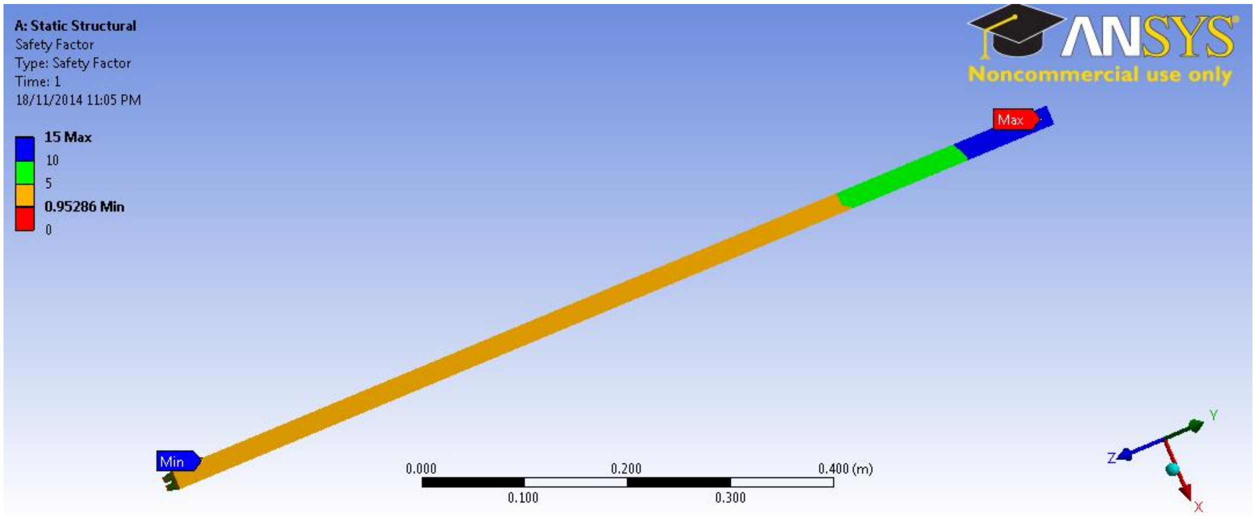


Figure 14: Safety factor along the strip when an 18 N force is applied.

Because the factor of safety is below one in the orange region, the FEA suggests that the strip will fail in this area when an 18 N force is applied.

Figure 15 shows the von Mises stress distribution along the strip when the same 18N force is applied.

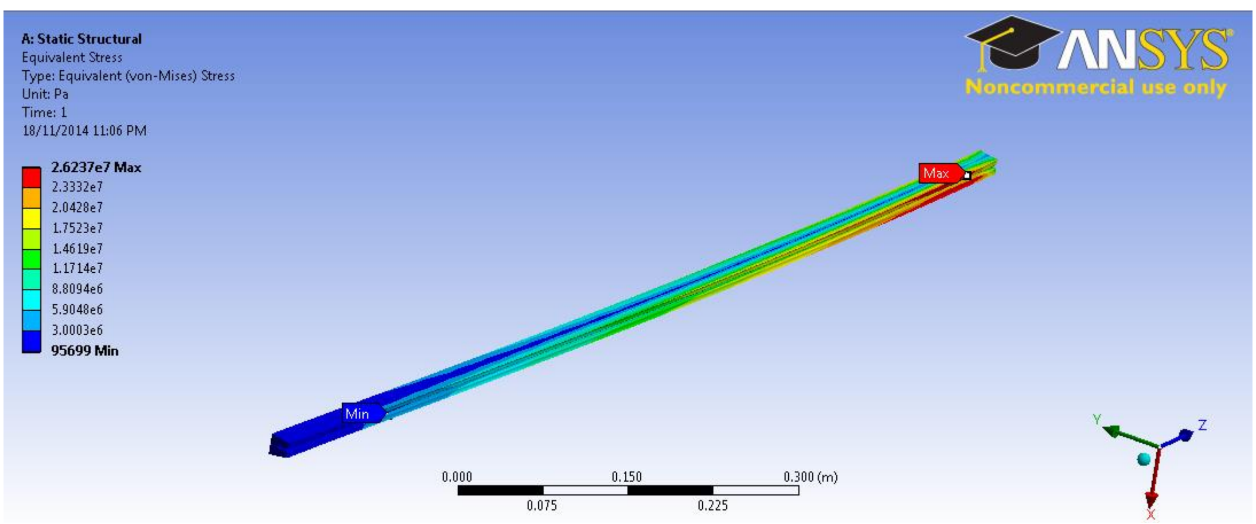


Figure 15: Von Mises Stresses of the strip with an 18 N force applied.

This figure shows a maximum stress of 26.23 MPa, which is higher than the yield stress for LDPE. Therefore the starter strip will permanently deform or possibly fail under this applied force. Finally, Figure 16 shows the total deformation of the starter strip under the same 18 N force.

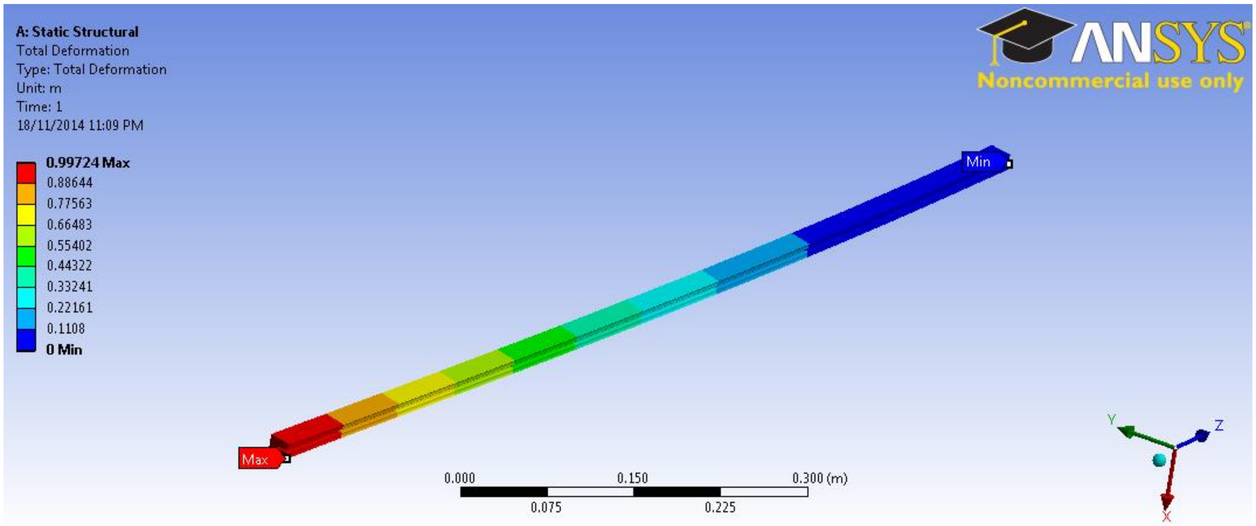


Figure 16: Total deformation of the strip with an 18 N force applied.

The highest total deformation is approximately one meter which is an extremely high value; it indicates that a force of 18 N has a very important impact on the strip.

After analyzing the effect of applying a force of 18 N on the strip and realizing that it will cause the strip to break, we applied a lower force, 15 N. We studied the same criteria as the previous analysis, which are the safety factor, the equivalent stresses and the total deformation that are presented in the following next three figures (Figure 17, Figure 18 and Figure 19).

Figure 17 represents the safety factor of the strip with a force of 15 N applied to it.

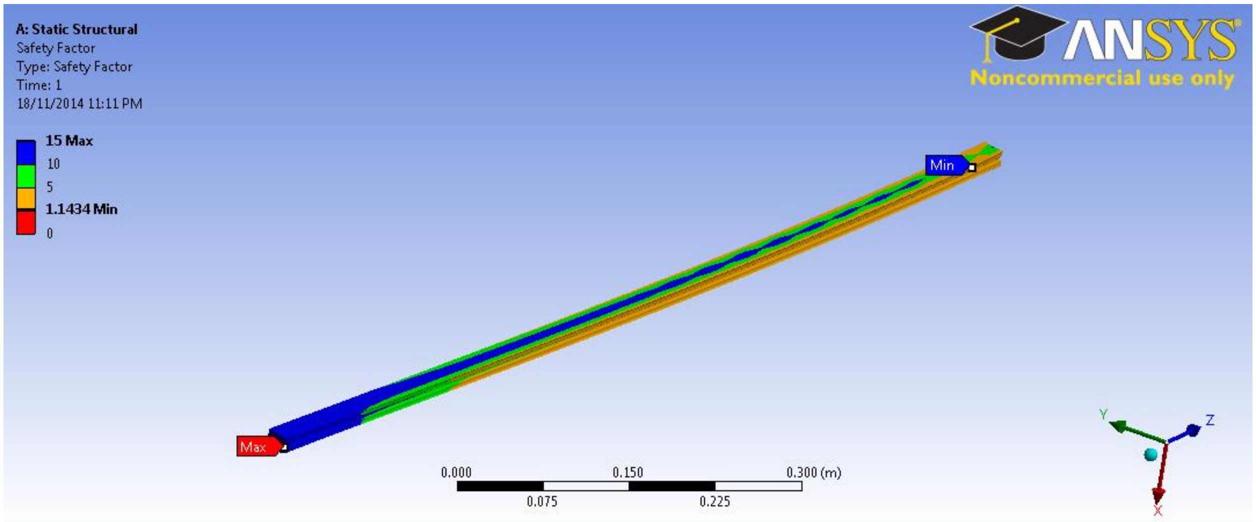


Figure 17: Safety factors of the strip with a 15 N force applied.

The lowest safety factor is 1.14 which is above 1, which means that the strip will not break instantly when a force of 15 N is applied but the lowest safety factor is still lower than 2. This means that the strip is not considered safe for a force of 15 N applied to the strip.

Figure 18 represents the maximum stress of the stick when a force of 15 N is applied:

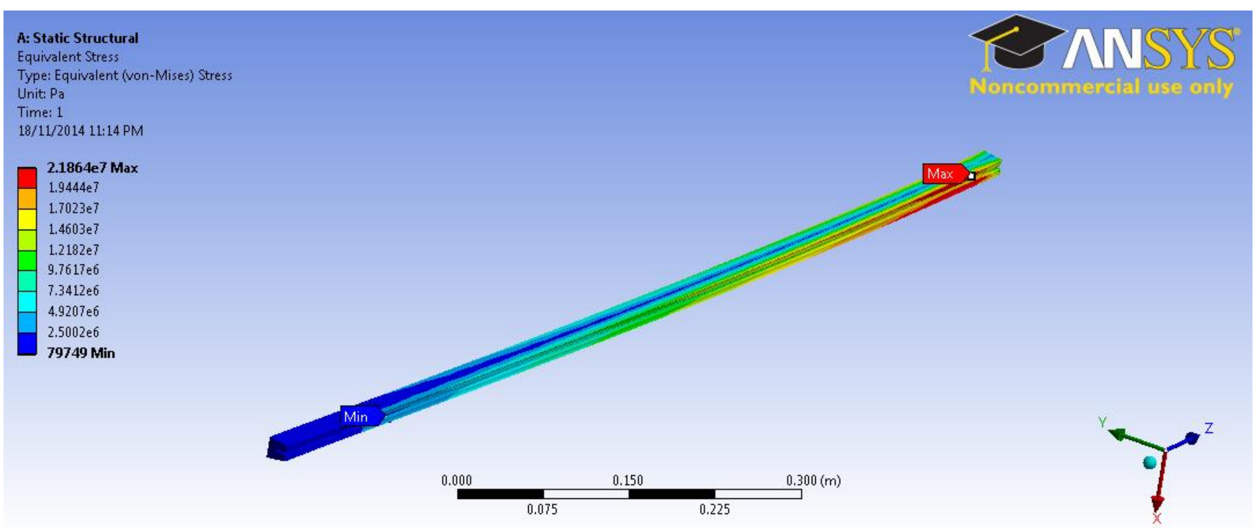


Figure 18: Von Mises stresses of the strip with a 15 N force applied.

We can see in Figure 18, that the maximum stress is 21.87 MPa located at the non-fixed end of the stick. The maximum stress of 21.87 MPa is higher than the yield stress for LDPE which is 12 MPa, so we can say that the starter strip will yield when a force of 15 N is applied.

In the Figure 19, the total deformation of starter strip is presented with the same force of 15 N being applied:

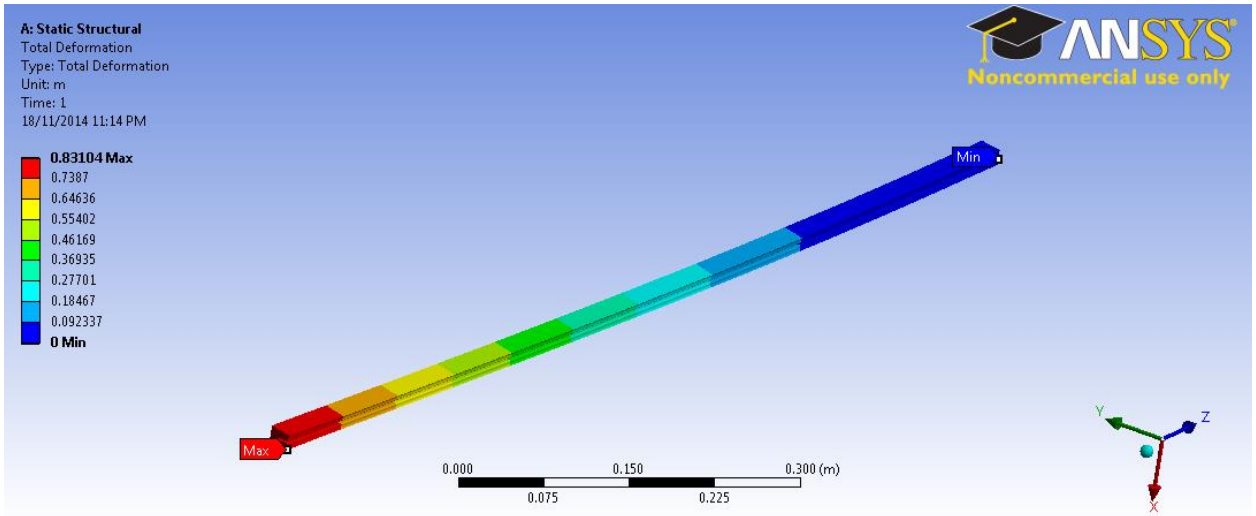


Figure 19: Total Deformation of the strip with a 15 N force applied.

In Figure 19, we can see that the maximum deflection is 0.83 meter which is lower than the maximum deflection obtained when the force of 18 N was applied. It is still a very high value which shows that a 15 N force has a very high impact on the strip.

After analyzing the effect of applying a 15 N force on the strip and realizing that it has a very important impact on the strip, we applied a lower force of 10 N. We studied the same criteria as the previous analysis, which are the safety factor, the equivalent stresses and the total deformation that are presented in the following next three figures (Figure 20, Figure 21 and Figure 22).

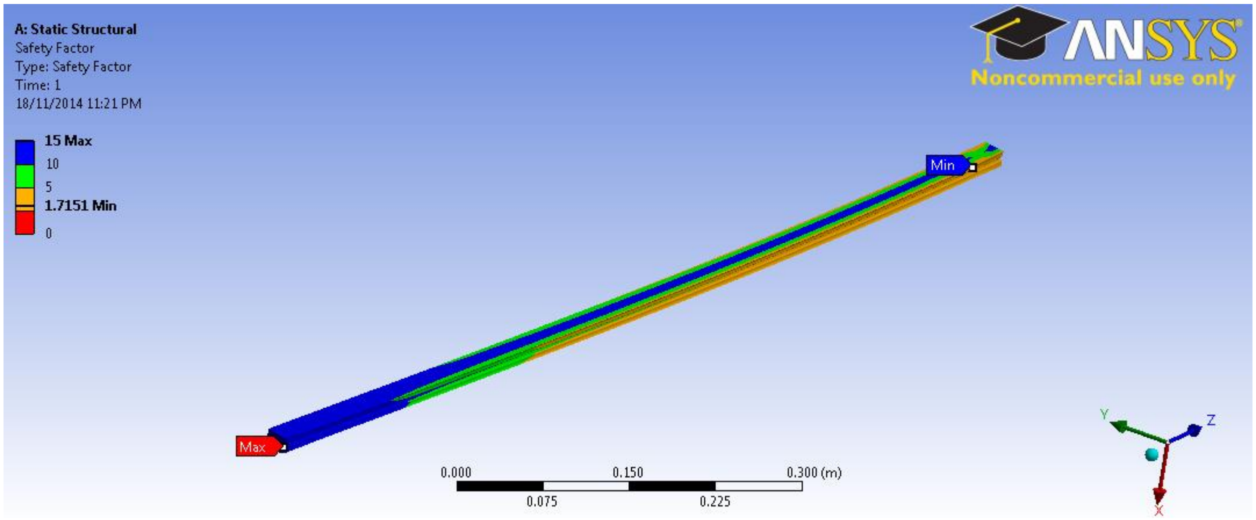


Figure 20: Safety factors of the strip with a 10 N force applied.

The lowest safety factor is 1.71 , which is higher than all the previous safety factors analyzed but the safety factor is still below 2 which is the minimum safety factor required for a safe design based on any application.

Figure 21 represents the maximum stress of the stick when a force of 10 N is applied.

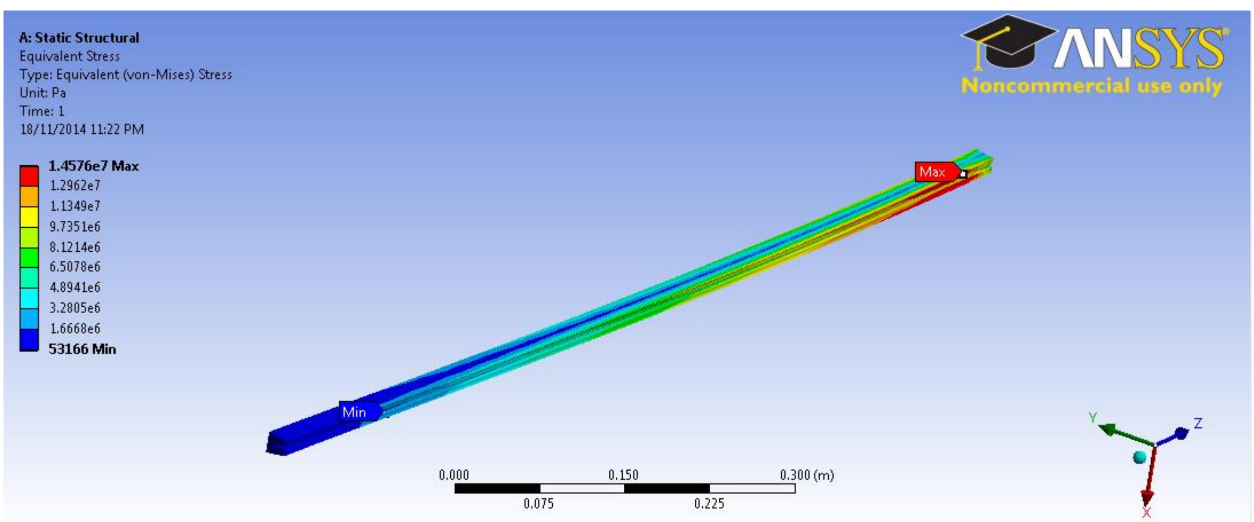


Figure 21 : Von Mises stresses of the strip with a 10 N force applied.

We can see in Figure 21 that the maximum stress is 14.58 MPa which is very close to the yield stress of LDPE that is 12 MPa.

In Figure 22, the total deformation of starter strip is presented with the same force of 10 N being applied:

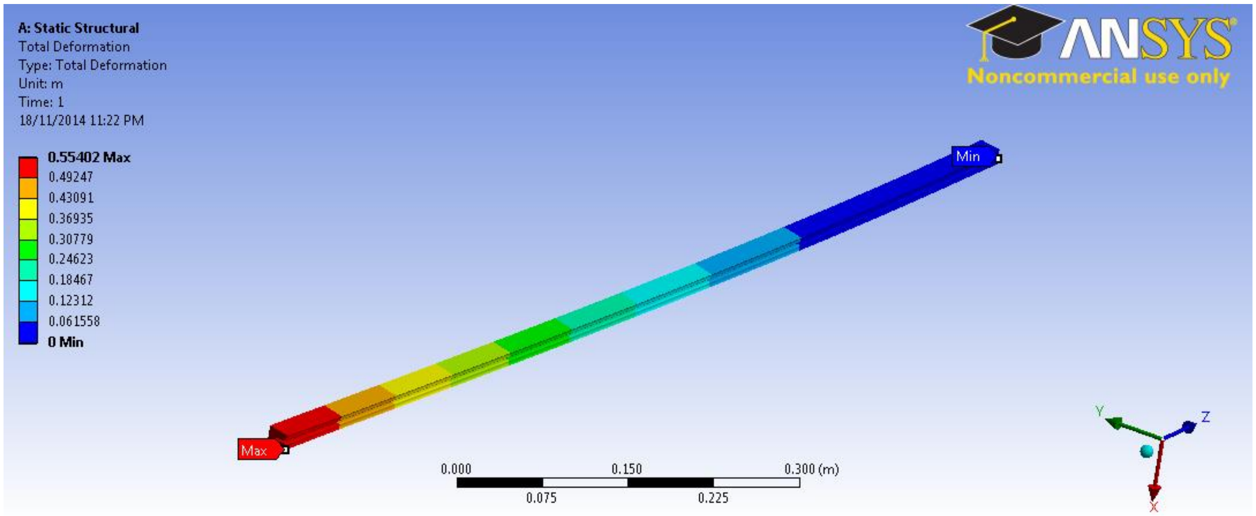


Figure 22: Total deformation of the strip with a 10 N force applied.

In Figure 22, we can see that the maximum deflection is 0.55 meter which is a more reasonable maximum deflection than the previous values obtained (i.e. 1 m and 0.83 m) when the forces of 18 N and 15 N were applied.

After analyzing the effect of applying a 10 N force on the strip and realizing that it has a more reasonable impact on the strip, we applied a lower force of 5 N since the safety factor was still below 2. We studied the same criteria as the previous analysis, which are the safety factor, the equivalent stresses and the total deformation that are presented in the following next three figures (Figure 23, Figure 24 and Figure 25).

Figure 23 represents the safety factor of the strip with a force of 5 N applied to it.

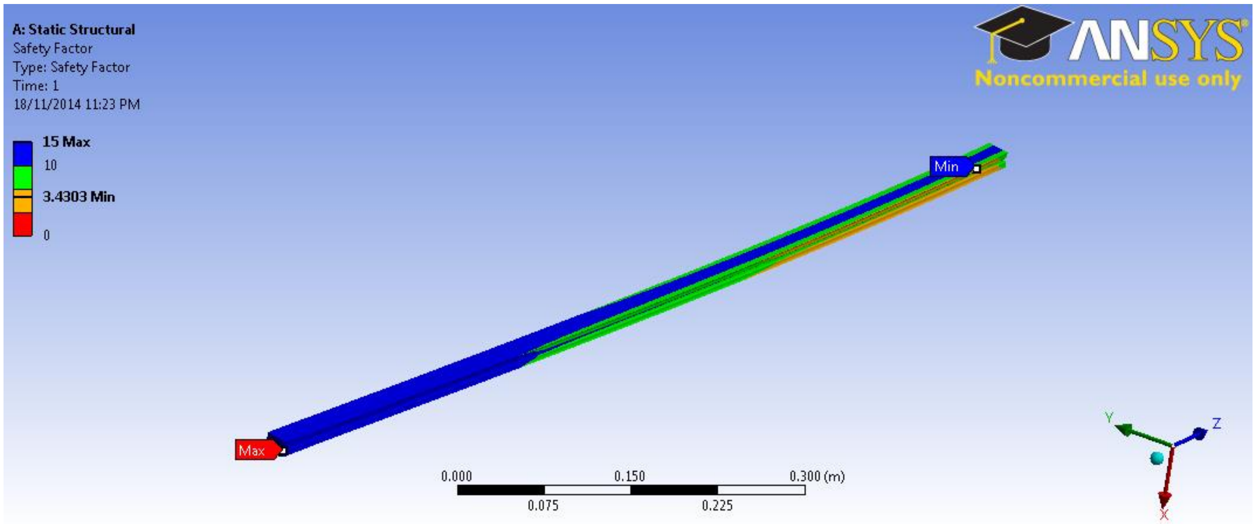


Figure 23 : Safety factors of the strip with a 5 N force applied.

The lowest safety factor is 3.43, which is higher than the minimum safety factor required for a safe environment for our application which is 2.

Figure 24 represents the maximum stress of the stick when a force of 5 N is applied.

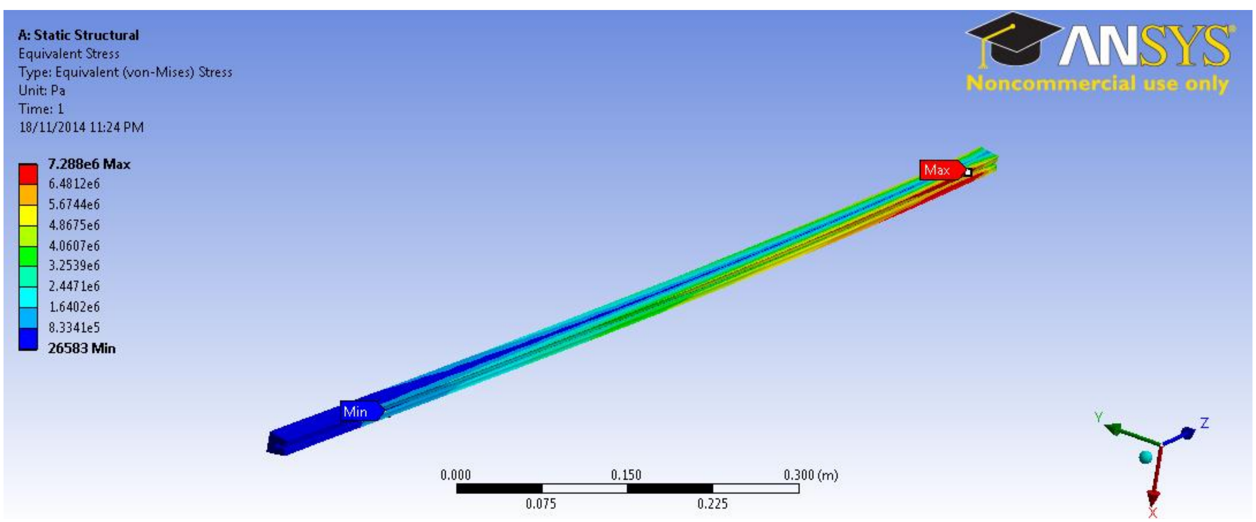


Figure 24: Von Mises stresses of the strip with a 5 N force applied.

We can see in Figure 24 that the maximum stress is 7.29 MPa which is lower than the yield stress of LDPE, which is 12 MPa.

In Figure 25, the total deformation of starter strip is presented with a force of 5 N being applied:

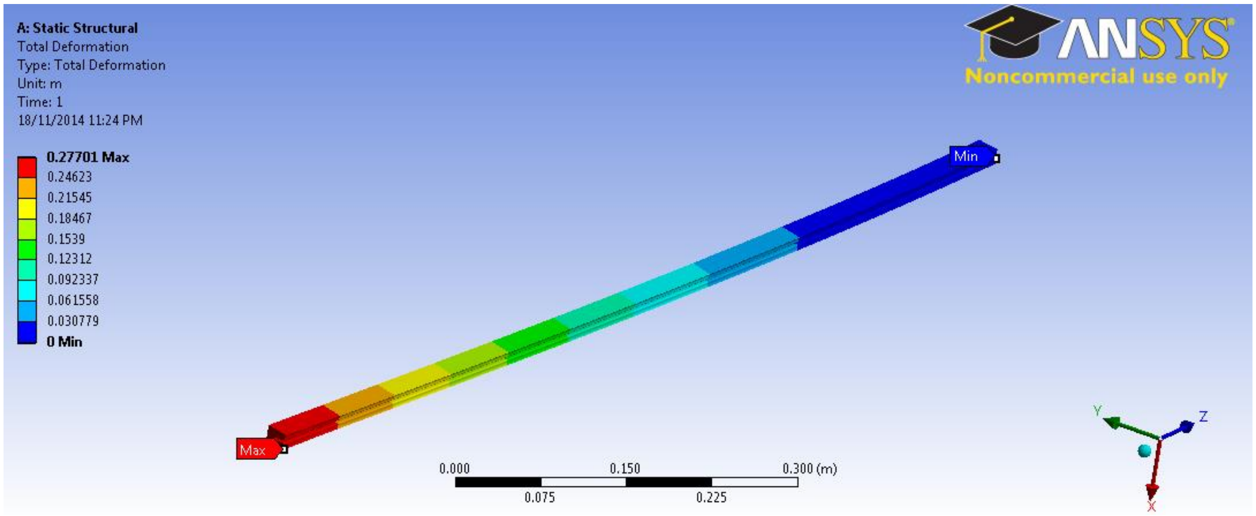


Figure 25: Total deformation of the strip with a 5 N force applied.

In Figure 25, we can see that the maximum deflection is 0.28 m which is a reasonable maximum deflection than the previous one obtained (1 m, 0.83 m and 0.55 m) when the respective forces of 18 N, 15 N and 10 N were applied.

The finite element analysis results were summarized in TABLE XXII.

TABLE XXII : FINITE ELEMENT ANALYSIS RESULTS

Force	Safety Factor	Maximum Stress (MPa)	Maximum Deflection (m)
18	0.95	26.23	1
15	1.14	21.87	0.83
10	1.71	14.58	0.55
5	3.43	7.29	0.28

Based on the finite element analysis specified in the table above, and the criteria considered during our analysis, the range of force applied without causing the stick to yield is between 0 and 15 N.

After going through the details of the experiments and analysis to find the required force for the nickel removal, we summarized all our values in the following section.

The results for the force values from the theoretical, finite element analysis and the experimental are summarized in this section for direct comparison. TABLE XXIII lists the results.

TABLE XXIII: FORCE RESULTS FOR DIFFERENT METHODS

Method	Trial number	Force (N)
Theoretical	Trial 1	5.65
Finite element analysis	Trial 1	18
	Trial 2	15
	Trial 3	10
	Trial 4	5
Spring Experiment	Trial 1	45.30
	Trial 2	96.45
	Trial 3	64.94
	Trial 4	75.40

The force values attained from various methods have a wide range from 5.65 N to 96.4 N. The experimental values take into account a dynamic force. On the other hand, finite element analysis and the theoretical analysis solely consider the static force which is why the force values are considerably lower. Based on the results, we will base our further calculations on the highest force value attained.

4.2 DRUM DESIGN

The tilted tumbler has been designed as a dual chamber design which includes outer and inner cylinders for specific purposes. The inner chamber is perforated with two inch diameter holes and the rotating motion of the tumbler will allow the product to be collected into the outer chamber due to gravity. In other words, as the drum turns and tumbles the LDPE strips, the pieces of nickel smaller than two inches in diameter will fall through the perforations and will be collected into the outer chamber. Once the tumbling cycle ends, the nickel will be recovered from the outer chamber with the help of a discharge door that will be further outlined in Section 4.5.3.

4.2.1 DIMENSIONS OF THE OUTER AND INNER CYLINDERS

The dimensions of the outer and inner cylinders were determined based on various manufacturers' recommendations such as Didion and Applied Chemical Technology. As the length of the strips is 2.5 feet and 3.75 feet in length, the representatives from Didion recommended that the ideal length of the drum would be 5 feet. In order to accommodate a minimum of 500 strips, the required inner diameter was found to be 4 feet. The outer cylinder's diameter was selected as 5 feet in order to give sufficient room to collect the nickel product. These dimensions were recommended by experts in the field of rotary drums as it is similar to the concept of our design. Figure 26 is a rendered image of the outer and inner cylinder.

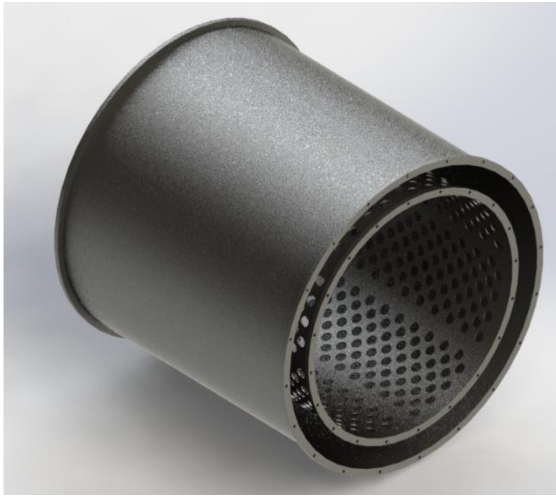


Figure 26: Render of inner and outer cylinder. The length of both cylinders is 5 feet.

The inner cylinder includes a meshed screen in order to allow the nickel to be collected by the surface of the outer cylinder. The diameter of the perforations was selected as two inches to provide enough space for larger rounds of nickel to be fall off. Figure 27 illustrates a rendered image of the inner cylinder showing the perforations with a two-inch diameter. Figure 28 is 2D engineering drawing showing the dimensions of the internal cylinder.

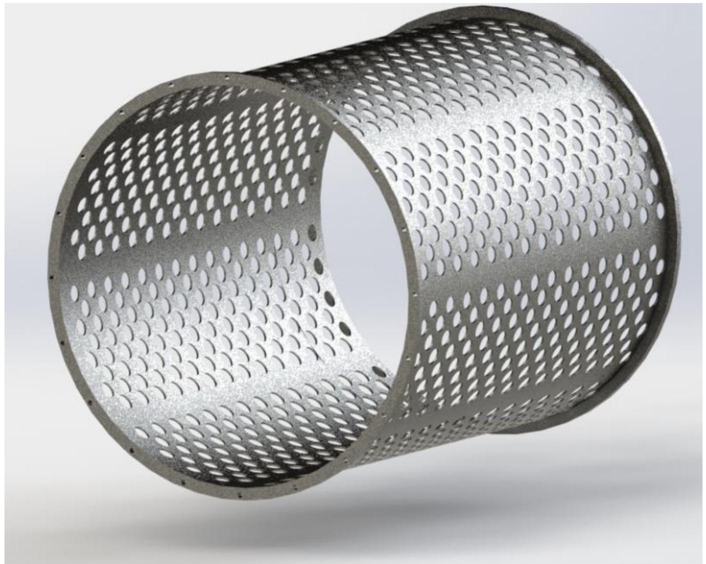


Figure 27: Inner cylinder of the Tilted Tumbler showing the perforations.

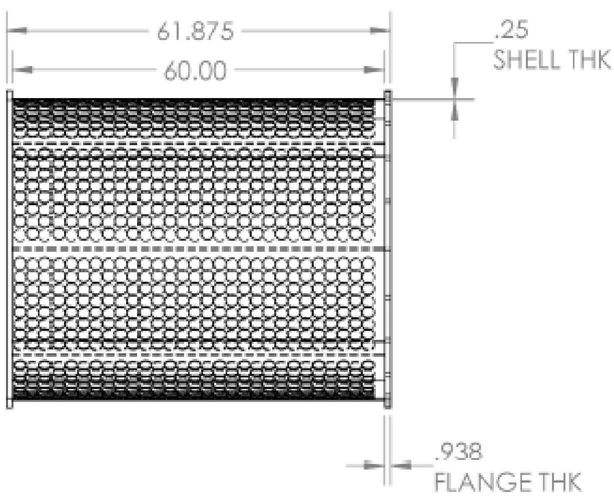


Figure 28: Sketch of the internal cylinder with length and thicknesses.

Both the inner and outer cylinders are critical parts of the tilted tumbler design. Once the dimensions of the drum were determined, the loading capacity and the rotational speeds were calculated and are discussed in the following sections.

4.2.2 TUMBLER TILT

In order to determine a suitable angle for tilting of the tumbler, we conducted a basic force analysis on the surface friction between LDPE strips and the tumbler. To simplify the complex situation of a tumbler rotating with hundreds of starter strips, we assumed the situation was comparable to a mass of simple shape on an inclined plane. Because the starter strips and nickel will be falling out as the tumbler is operating, we used a kinetic coefficient of friction for calculations, as the strips and nickel will already be moving due to rotation. The process for determining a suitable incline for the tumbler barrel is explained below. The free body diagram for the simplified starter strips sliding down the inclined tumbler is shown in Figure 29.

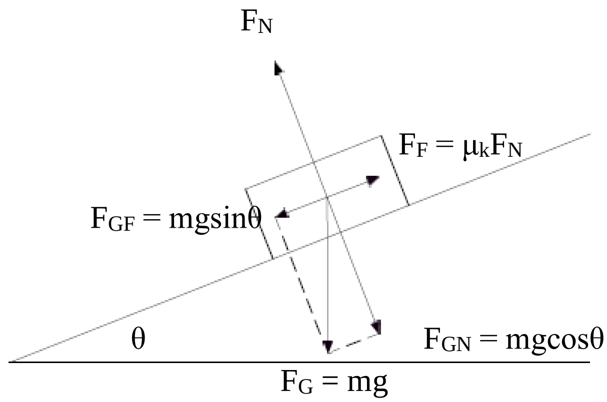


Figure 29: Free body diagram of friction and gravity forces acting on a mass on an inclined plane.

The force due to gravity was decomposed into the components parallel (F_{GF}) and normal (F_{GN}) to the inclined plane, so that the minimum angle, θ, for the incline could be determined. Because the mass cannot move in the direction normal to the plane, F_N is equal to F_{GN} as shown in the figure. Then the minimum requirement for movement of the mass down the plane is for F_{GF} and F_F to be equal. After equating these, the only unknown variable is θ, which can be solved for by rearranging the equation as such:

$$F_{GF} = F_F$$

$$mgsin\theta = \mu_k mgcos\theta$$

$$\frac{sin\theta}{cos\theta} = \frac{mg\mu_k}{mg}$$

$$\theta = \tan^{-1}\mu_k$$

Equation 5: Force balance on the incline with simplification

Friction coefficients vary greatly in practice and depend on a number of factors, including surface smoothness and quality. In regards to the starter strips in this project, their surface smoothness and quality varies greatly from strip to strip. As well, the amount of nickel stuck to each strip contributes to this surface friction and also varies greatly. Therefore, the dynamic coefficient of friction, μ_k, used in these calculations was determined by averaging values from a number of sources, which are detailed in Appendix B-4. This averaged value used for μ_k was 0.19, which gave a minimum tumbler incline value of 11.31°. As this is the minimum value estimated to cause the strips and nickel to unload from the tumbler, to ensure the strips and nickel do exit the tumbler completely we use a slightly steeper tumbler incline of 15° in our design. This also should account for some of the inaccuracies in the estimated coefficient of friction and the simplifying assumptions of this problem.

The overall height for the tumbling system with all parts assembled together will be 9.4 feet, which is below our height constraint of 10.75 feet. The reason for tilting the tumbler was to ensure the nickel and the strips fall out through the discharge door separately. After determining the need and angle of tilt of the tumbler, we will analyze the needed force for the nickel removal of our design and how does it affect other aspects of the tumbler design.

4.2.3 MATERIAL SELECTION

Selection of materials and manufacturing process are important aspects of engineering design. As part of our constraints, galvanized steel and aluminum cannot be used as per our client. As the rotary drum will be manufactured with a total capacity of 500 strips, the material should be strong enough to withstand the weight of the strips, but also be as light as possible to ensure that the drive system is able to rotate the drum. As a summary, the following factors were used to select the material:

- Weight
- Strength
- Resistance to fracture
- Corrosion resistance
- Cost
- Durability

Most rotary drums are fabricated with carbon steel or stainless steel. However, there are various grades of carbon steel and stainless steel and further analysis was conducted to determine the optimum material. Table XXIV includes the metrics for the factors considered during our material selection.

Table XXIV: SPECIFICATIONS FOR CARBON STEEL AND STAINLESS STEEL

Property	Carbon Steel (mild steel)	Stainless Steel[5]
Density	0.284 lb/in^3	0.29 lb/in^3
Ultimate tensile strength [13]	450 MPa	860 MPa
Resistance to fracture [14]	140 MNm$^{-3/2}$	195 MNm$^{-3/2}$
Corrosion resistance [15]	1	2 (better)
Cost of hot rolled plate [16] [17]	$546 per tonne	$3065 per tonne
Durability [18]	1	2 (better)
Welding/Bendability [18]	2 (better)	1

The most important factor is the weight of the material and the density of mild steel which is generally carbon steel is 0.284 lb/in^3 [19] and stainless steel is 0.29 lb/in^3 [20]. The difference in density and ultimate tensile strength between the two types of material is fairly negligible; therefore it is difficult choosing between the two. However, cost is undoubtedly one of the most important factors and stainless steel is exceptionally expensive than carbon steel. But Stainless steel is highly corrosion resistance. The client indicated the environment the system

[5] The metrics determined in the table were all determined for stainless steel grade 316SS as it is the most common grade of stainless steel.

will be operation is highly corrosive. In order to make it durable and perform successfully stainless steel would be a better option. Since it was extremely difficult to decide which material the drum will be made of, a decision-making matrix was developed to properly select the type of material. TABLE XXV illustrates the decision-making matrix that was used for material selection.

TABLE XXV: DECISION-MAKING MATRIX FOR MATERIAL SELECTION

Criteria	Weight	Carbon Steel		Stainless Steel	
Density	15%	Mark	**8**	Mark	**7**
		Total	**1.2**	Total	**1.05**
Ultimate Tensile Strength	15%	Mark	**3**	Mark	**10**
		Total	**0.45**	Total	**1.5**
Resistance to fracture	10%	Mark	**5**	Mark	**10**
		Total	**0.5**	Total	**1**
Corrosion resistance	10%	Mark	**2**	Mark	**10**
		Total	**0.2**	Total	**1**
Cost of hot rolled plate	30%	Mark	**10**	Mark	**0**
		Total	**3**	Total	**0**
Durability	10%	Mark	**0**	Mark	**10**
		Total	**0**	Total	**1**
Welding/Bendability	10%	Mark	**7**	Mark	**6**
		Total	**0.7**	Total	**0.6**
Total			**6.05**		**6.15 DEVELOP**

Based on the results from the decision-making matrix, stainless steel scored higher than carbon steel. The cost is an effective factor but more material will be required to make the Carbon steel structure as durable therefore the mass and cost will go up considerably. Therefore stainless steel is a better option and it was used as the material for the two concentric tumblers. The grade of stainless chosen was 316 stainless steel.

4.2.4 DRUM SHELL THICKNESS

As the drum rotates, a force is transmitted by the LDPE strips and the nickel to the shells of the tumbler. In order to ensure that the drum does not fail, an analysis was done to determine the shell thickness of the inner and outer cylinders.

As the drum rotates, the pressure being transmitted by the LDPE strips and the nickel product is quite high. In order to ensure that the drum does not fail, supplementary analysis was completed to determine the shell thickness of the inner and outer cylinders. In order to determine the shell thickness, several assumptions were made:

In order to determine the shell thickness, several assumptions were made:

- The stresses on the inner drum will be higher than the outer drum because both the weight of the LDPE strips and the nickel product will be exerting a force on the inner walls of the drum.
- Calculations to determine minimum thickness of the drum will be made solely for the inner drum as the stresses are assumed to be higher.
- The thicknesses for the outer and inner walls will be identical to each other.
- It is assumed that both cylinders are thin-walled based on the fact that the thickness will be less than a tenth of its radius. Thickness will be as small as possible to reduce overall weight of the tumbler.

Based on our assumption that the drum will be thin-walled (Figure 30), the hoop stress equation was used which also accounts for the internal pressure on a cylindrical vessel.

Figure 30: Thin-walled Cylinder with Internal Pressure [10]

The generic hoop stress formula is expressed in Equation 6, where *P* is the internal pressure, *t* is the wall thickness, *D* is the diameter and σ_θ is the hoop stress.

$$\sigma_\theta = \frac{PD_m}{t}$$

Equation 6: Hoop Stress Equation

For the case of our rotary drum, Equation 6 can be rearranged to calculate the minimum thickness required. The thickness calculations is shown Equation 7 and it was important to note that this formula includes additional variables.

$$t_s = \frac{PD}{2FJ + P}$$

Equation 7: Shell Thickness Equation [10]

Prior to solving, the parameters of the Equation 7 are defined in TABLE XXVI.

TABLE XXVI: PARAMETERS FOR THICKNESS CALCULATIONS

Working pressure (WP)	14.69 psi
Design pressure (P)	22.03 psi
Diameter of the inner chamber (D)	60 inches
Allowable stress (F)	73244 psi
Joint Efficiency (J)	0.85

The table above specifies the values used for the design pressure, the diameter of the inner chamber, the allowable stress and the joint efficiency. The design pressure was calculated using the working pressure multiplied by 1.5 which is the recommended value based on the code ASME Section VIII, Div. 1. Furthermore, the joint efficiency of 0.85 was also taken from Table UW-12 from the same code [12]. The joint efficiency was selected based on thickness calculations seen for rotary dryers[6] [10]. With the parameters explained and defined, Equation 7 was used to calculate the thickness required for the inner chamber of the drum.

$$t_s = \frac{122.03 \text{ psi} \times 60 \text{ inches}}{(2 \times 73224\, psi) + 22.03\, psi} = 0.0106\, inches$$

[6] The comparison was made to rotary dryers because they use the same mechanism, and based on advice from other manufacturers (Didion and Applied Chemical Technology), it is a valid assumption to make.

The thickness found above does not include any factor of safety. Therefore, we decided to add a safety factor of 10 and also an additional 0.100” for corrosion allowance. The thickness of both cylinders was determined to be ¼”.

4.2.5 INTERNAL TUMBLER SUPPORTS

A support structure is required to support the inner tumbler cylinder within the outer drum. Both tumblers rotate at the same angular velocity and are bolted on one end by a common plate. The bolts will take some amount of the load for the inside tumbler but because of the rotating action, direct supports joining the two tumblers are necessary to ensure proper function of the design and to reduce the risk of failure. Figure 31 shows the unsupported inner tumbler floating inside the outer tumbler.

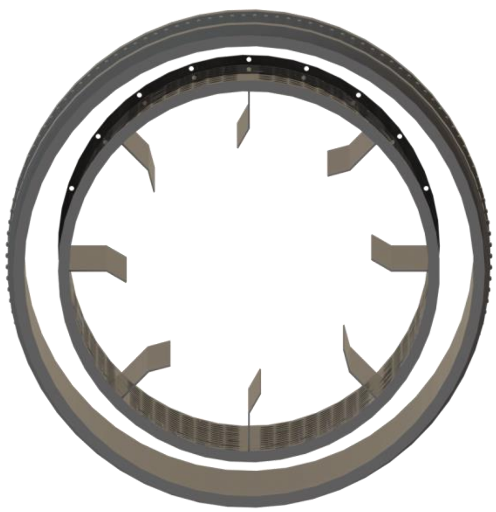


Figure 31: Side view of tumbler drums without supports.

The material of the supports was chosen based on the approximate strength required and the project constraints which preclude the use of galvanized steel or aluminum. The material used for the construction of the two tumblers is 316 stainless steel. Because stainless steel has better corrosion resistance properties and good wear capabilities compared to other low grade steels, 316 stainless steel will also be used for the construction of the supports. The primary reason that led to this decision is that welding the supports will increase the structural integrity. The supports will be welded to the external tumbler and the internal tumbler will sit on the supports. Even though lower grade material will be able to handle the load adequately, welding different steels together adversely affects the corrosion resistance characteristics of stainless steels [21].

We chose the number of supports for the tumbler to be two sets of four, equally spaced every 90° along the surface of the tumbler. This number was chosen based on the stability they provide to the tumbler. It was important to minimize the size and number of supports, as they add mass and cost to the design. The center of the supports will be 1.67 ft. from each end of the tumbler as shown in Figure 32. The supports will also help in reducing bending of the tumbler.

In order to design the supports, the following assumptions will be used:

- The cylinder will contain about 500 strips with an average of 1.5kg of nickel attached per strip,
- The tumbler can be simplified as a two dimensional structure, where the two parallel supports will be able to support the entire load of the tumbler.
- The dynamic system can be represented sufficiently by a static analysis.

The factor of safety used for design was five, to compensate for the assumptions. The 0.4 kg mass, M, of the longer starter strips will be used for the calculations to take into the account the more extreme loading scenario.

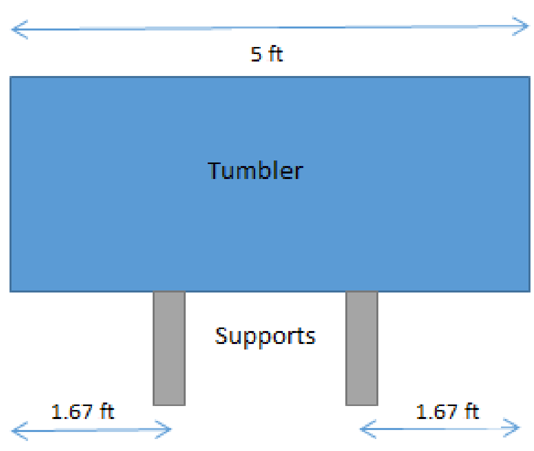


Figure 32: Positions of the supports with respect to the tumbler.

The ultimate strength of 316 stainless steel is 860 MPa. Equation 8 below was used to calculate the allowable stress of the supports when the factor of safety is taken into account. This allowable stress was found to be 172 MPa.

$$Allowable\ Stress = \frac{Ultimate\ Strength}{Factor\ of\ Safety}$$

Equation 8: Determination of allowable stress for a factory of safety.

The masses of the system are as follows:

- Mass of tumbler = 470 kg
- Mass of 500 of the 45” length starter strips = 200 kg
- Mass of nickel on 500 starter strips = 750 kg

The total combined mass of these components is then 1420 kg, resulting in a total load of 1420 N on the supports. The supports will be loaded axially, therefore the force will be divided by half for each support. The area required to hold the support will be given by Equation 9 below.

$$Area = \frac{Force}{Allowable\ Stress(\sigma)}$$

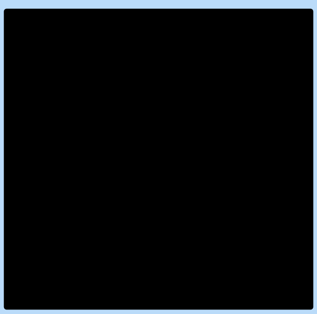
Equation 9: Calculation of contact area between supports and tumblers.

$$= \frac{\left(\frac{13916}{2}\right)N}{172\ X\ 10^6 Pa} = 4.045\ X\ 10^{-5}\ m^2\ or\ 40.45\ mm^2$$

The above calculation determined that the area of contact between the support member and the tumbler should be at least 40.45 mm^2 or 1.6 in^2. In order to obtain stability the length and breadth of the beam should be maximized. In selection of the type of support to be used, three shape types were looked at that reduce the area while maximizing the length and breadth. These shape types were W-flange, hollow square channels and angles. Considering the standard sizes available, we chose the length of the support to be around 12, as all the beams in that length range also provide an area greater than 1.6 in^2.

Table XXVII shows the dimensions of the different types of columns available in 12 inch lengths. Comparison of the different types of columns suggested the hollow square type as the best suited for our design. It has a maximum length and breadth of 12”x10”, while maintaining a minimum cross-sectional area of 14.6 in^2 for the 0.375 inch thick column. However because it is to be applied to the inside tumbler which is perforated, nickel may accumulate and become trapped in the hollow section of the column during operation.

TABLE XXVII: DIMENSIONS OF DIFFERENT TYPES OF SUPPORT COLUMNS [22], [23], [24]

Angle		**$d \times b_w$ (in x in)**	**t (in)**	**Sectional Area (in^2)**
		12x12	1	22.9
		12x12	1.375	30.9
W- Flange		**$d \times b_f$ (in x in)**	**t_w (in)**	**Sectional area (in^2)**
	W12x53	12.06 x 10	0.345	15.6
	W12x79	12.38 X 12	0.37	23.2
Hollow Square		**B x B (in x in)**	**T (in)**	**Sectional area (in^2)**
		12x10	0.375	14.6
		12x10	0.5	19

After removing the hollow square support, the W-flange column was the best option. The area is 15.6 in^2 while the depth (d) and width (b_f) are equivalent to that of a hollow square. The

W12x53 columns were therefore chosen for use in the design. The length of the support columns should be 6 inches long and cut to fit the curved surfaces of the tumblers. The length of the column compared to its cross-section is small; therefore there were no concerns in regards to buckling. Figure 33 and Figure 34 depict two different views of the internal supports in the tumbler model. Figure 33 shows a close-up section view of the internal supports and their location along the length of the tumbler drums. Figure 34 is an open side view of the tumblers showing the radial location of the sets of supports.

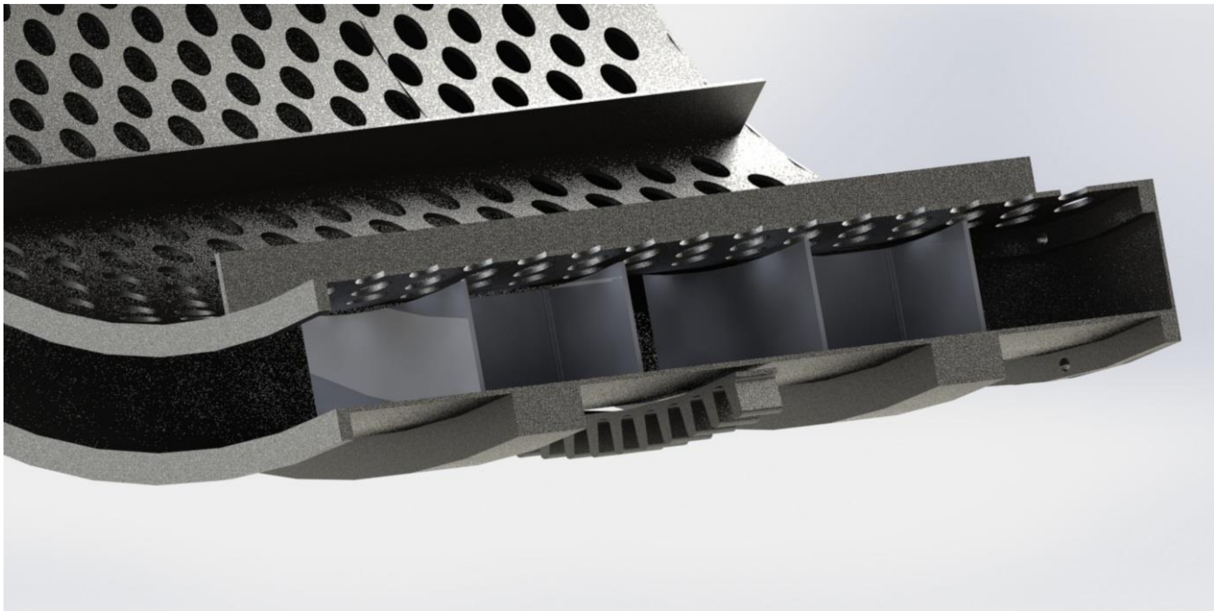


Figure 33: Illustrates the internal supports holding the internal cylinder. As shown above, the supports are shaped like I-beams.

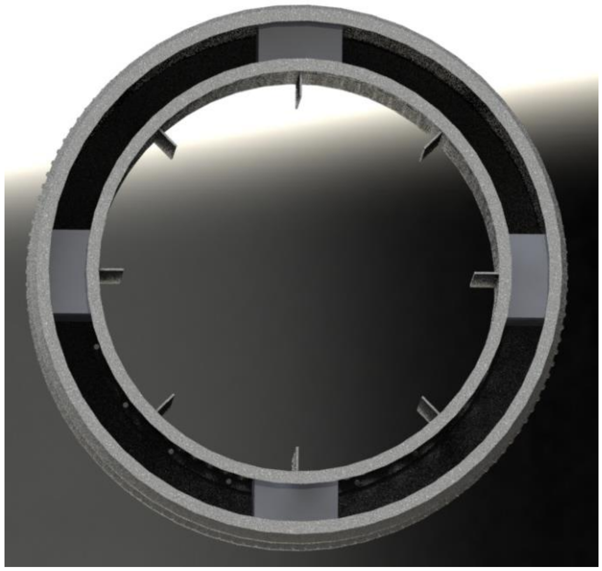


Figure 34: Each of internal supports is placed at 90 degrees from one another to provide optimal support.

These preliminary calculations gave us an estimate of the required size and shape of the supports. These results were then validated by modelling the supports in SolidWorks and conducting a numerical analysis with ANSYS.

4.2.6 RADIAL PLATES

The radial plates are located on the inner tumbler drum and attached to the inside face. The plates pick up the strips as the tumbler rotates and allows them to be carried to a certain height before falling back down to the bottom of the tumbler. This action imparts a certain amount of impact on the strips as they fall, and the nickel will be removed.

The plate is angled at the free end as shown in Figure 35, so the LDPE strips travelling radially on the plate reach an extended height for maximum impact as they drop. This angle is called the flight tip angle, α_2. It is based on the angle of repose for granular material that is dried in rotary dryers based on similar design concept [25]. For the case of LDPE strips, the properties of rigid solids are more general, therefore an angle of 120˚ was selected. The angle of flight base, $\alpha_{1,}$ is 90˚ which is generally the angle used for rigid solids and bulk solids.

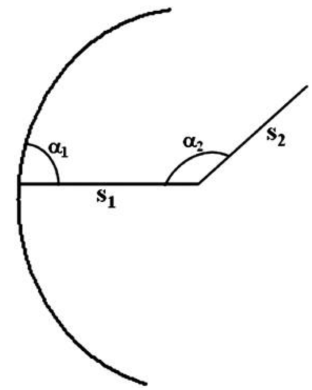


Figure 35: Flight geometry diagram for radial plates [26].

The length of the radial plate was selected based on the length of the internal tumbler which is five feet in length. So the plates will be about inch shorter to allow half an inch clearance on either side. So the length of the plate is 4 feet 11 inches. The width of the plate was decided by looking at industrial dryer designs of similar diameters. The range of base length, s_1, for industrial dryer designs was between 1.5 and 3 inches [26]. As the starter strips in our design are larger than the solids relevant to the industrial dryers in [26], we increased the value for s_1 to be five inches. Similarly, the flight tip length, s_2, was determined for industrial dryers and a value of three inches was chosen. A total of 8 plates will be equally spaced along the circumference of the inner tumbler. These radial plates will ensure proper collisions between the strips as they rotate in the tumbler. The material for the radial plates was chosen to be 316 stainless steel, as the plates are to be welded to the inside of the tumbler which is also 316 stainless steel.

The thickness of the plates was designed based on the loads acting on them. The force acting on each plate was estimated by dividing the total mass of the strips with nickel attached (calculated in Section 4.2.5) by eight and multiplying by the acceleration of gravity. The initial velocity of the strips due to the tumbler rotation was not considered for this calculation. As well, the loading due to impact was also not considered. These simplifications will be accommodated by using a factor of safety of four to ensure the risk of failure is mitigated. The thickness was found by using different values in SolidWorks FEA package until simulation results returned maximum deflection values below 0.1 mm. The optimal thickness value was found to be 0.5 inches, which is a standard metal plate thickness. The maximum deflection value for the plate under the force applied was 0.074 mm as can be seen in Figure 36.

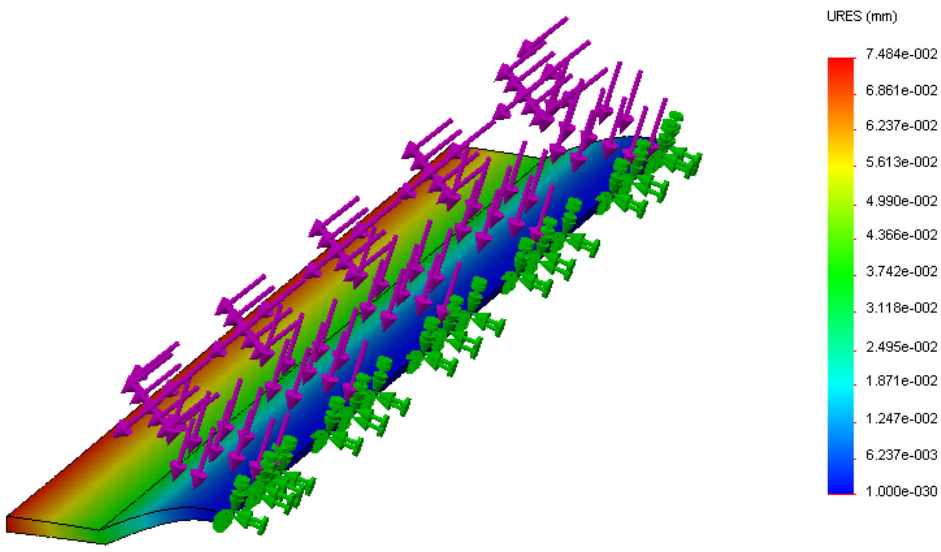


Figure 36: Radial plate deflection simulation

The stresses in the plate were also obtained from this simulation. The maximum von Mises stress under these loading conditions was found to be 8.374 MPa which is less than the yield stress of LDPE as can be seen by Figure 37.

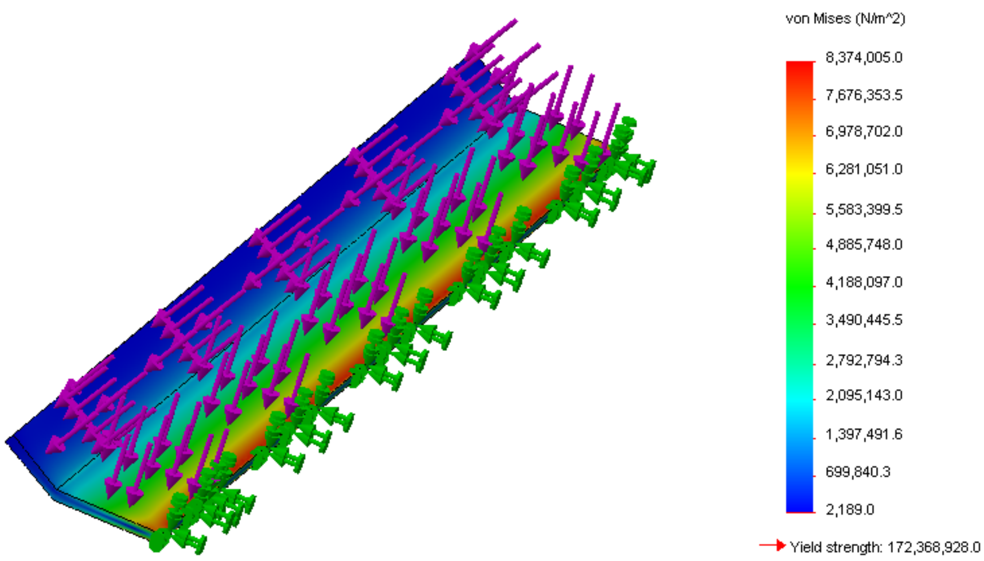


Figure 37: Radial plate von Mises stress simulation.

The final radial plates shown in Figure 38 will be constantly under dynamic load and in contact with the abrasive nickel.

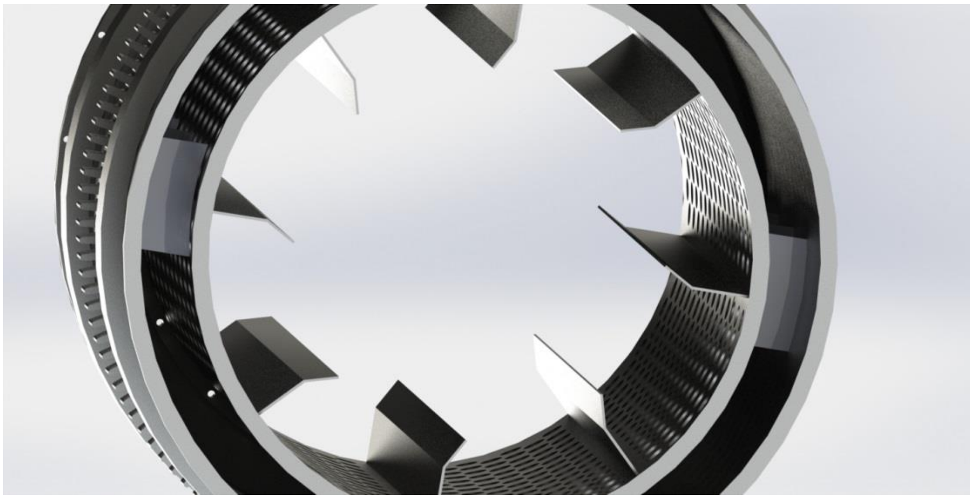


Figure 38: Radial plates view inside the tumbler

The design for the radial plates will be effective under the given loading conditions for the application.

4.3 TRANSMISSION SYSTEM

For any industrial tumbler, the drive components are similar to a rotary dryer. Generally, there are two types of arrangements for rotating equipment: a chain and a sprocket or a gear drive. For our design, we decided to implement a chain and sprocket drive because of its low cost. The second reason for selecting a chain drive is that gear drives are generally used for higher duty transmission and as our system rotating drum will be running at approximately 12.5 RPM, therefore medium duty power will be needed. Additionally, for any of the two arrangements, there are two tires on the rotary drive that sit on supports called "trunnion wheels". The trunnion wheels are part of the system in order to ensure that the drum is well supported which will be covered in Section 4.4. As for the drive system, we decided to add a large sprocket with a chain that is attached to a smaller sprocket being rotated by a reducer and a motor. The turning motor spins the gears that allow the rotation for the smaller sprocket. For our project, the transmission system was divided into two parts: selection of motor and gearbox and design of chain/sprockets.

4.3.1 SELECTION OF MOTOR AND REDUCER

The selection of motor includes multiple steps such as determining the driving mechanism, the calculation of motor speed and load being applied by tumbler to meet design specifications. The vendor selected for our motor is Baldor because it is a reputed motor and reducer manufacturer, and all products are readily available in Manitoba.

Prior to selecting the motor, we determined the required specifications to meet the demands of the tumbler. The following requirements were listed:

- The enclosure of the motor will be a totally enclosed fan-cooled (TEFC) design because the additional fan will draw air over the finned housing.
- The size of the motor frame was selected based on the required horsepower which was selected to be 7.5HP. This horsepower was selected based on one of the rotary drum manufacturers (Didion).
- For a single-phase power, the NEMA size number is 3[a] based on the horsepower of 7.5HP.

Based on the aforementioned specifications, Baldor's GCP25102 was selected as shown in Figure 39. Also, the motor's specifications are included in TABLE XXVIII.

Figure 39: Baldor's GCP25102

TABLE XXVIII: MOTOR SPECIFICATIONS

Model Number	GCP25102
Phase:	1
Voltage	115/230V
Output RPM	16
Torque	350 lb-ft
Ratio	102.4
Hertz	50/60
Poles	04
Insulation	F
Enclosure	TEFC
Cost (CAD)	$848

Baldor was contacted and they informed us that the motor and speed reducing component is included in one part and the price reflects that. In order to have the shaft, bearings and keys' selected, they already have OEM[7] parts for their motors. They advised that the motor and its entire assembly will cost approximately CAD $2998.

4.3.2 CHAIN AND SPROCKET ANALYSIS

The chain analysis performed for this design is different than the conventional way of determining the chain sizes. We began by assigning the diameter of the bigger sprocket as 60 inches because it will be located on the outer cylinder of the drum. The pitch of the chain was chosen to be 1.5 inches because it was the recommended value for 7.5 HP. In order to determine the parameters for the chain the catalog of a reputed roller chain manufacturer, Timken, was used [14]. TABLE XXIX summarizes the results computed for the chain and sprocket parameters.

[7] Original Equipment Manufacturer

TABLE XXIX: CHAIN AND SPROCKET PARAMETERS

Pitch size	1.5	inches
Number of teeth (Small Sprocket)	32	teeth
Number of teeth (large Sprocket)	126	teeth
Diameter (Small Sprocket)	15	inches
Diameter (large Sprocket)	60	inches
Horsepower	5	HP
Torque value	472.69018	lb-ft
Service factor	1.5	
Total HP	7.5	HP
Output RPM	12.5	RPM
Input RPM	50	RPM
Speed reduction ratio	4	

Based on the results above, the smaller size sprocket can be purchased from Timken however; the driven sprocket that is located on the drum will need to be specially fabricated. Generally, the maximum number of recommended teeth is 120; however in this case, the sprocket will have a total of 126 teeth. Figure 40 illustrates a typical transmission system for a rotary drum.

[redacted]

Figure 40: Transmission Drive Assembly on a Rotary Drum [13]

In order for the tumbler to rotate from the designed transmission system it must be positioned and supported appropriately.

4.4 TUMBLER ALIGNMENT AND SUPPORT

Misalignment is one of the most common issues with industrial tumblers. Generally, misalignment occurs when the base is not properly installed. This also engenders wear to the thrust and support rollers along with the riding rings. Therefore, detailed analysis is required to properly design the support for the drum which includes all the aforementioned components. Due to the complexity of design, we decided not to design the support assembly and purchase the components from a manufacturer which will include the following:

- Riding ring
- Support roller
- Thrust rollers

It was difficult to find a single vendor who is willing to provide the entire assembly therefore; we decided that the parts will need to be purchased separately.

4.4.1 RIDING RINGS

The riding ring adds structural support for the drum, and a place for pressure to be absorbed. The riding ring rides on the support roller. The thickness of the ring was determined to be four inches based on the total weight of the tumbler assembly.

4.4.2 SUPPORT ROLLERS

The support rollers as the name suggests support the weight of the drum and they are made out of steel. This type of roller is to be purchased from a vendor in China. As per their recommendation, the specifications of the support rollers were determined based on how they will accommodate the dimensions and the weight of our current system. The specifications are included in TABLE XXX.

TABLE XXX: SPECIFICATIONS OF ROLLER SUPPORTS

Product	Industrial steel roller alloy steel cold rolling support roller
Material	Stainless steel: 9-Cr, 2-Mo-R
Quantity	4
Outer diameter of support	200 mm

Figure 41 depicts the rollers that will be used to hold the weight of the tumbler. A total of four support rollers will be purchased, and each pair of rollers will be installed on both sides of the riding rings.

Figure 41: Support Roller

The support rollers were also placed at an angle of 30° as shown in Figure 42, because it is the standard location recommended for industrial tumblers for optimal support during the rotating action [27].

Figure 42: Location and angle of support rollers [27]

The support rollers are used in conjunction with thrust rollers, which are important for the alignment of the tumbler.

4.4.3 THRUST ROLLERS

The thrust rollers push on the riding ring to stop the drum from drifting, or moving horizontally. The thrust rollers were also selected based on a manufacturer's (CSM) standard sizes. The thrust roller sizes are selected based on the dimensions of the tumbler and its slope percentage. The slope percentage of our drum is approximately 26% and the length is exactly 5 feet. Based on these dimensions, a model was recommended by CSM.

Figure 43: Thrust Rollers from Astec [28]

For our design, we decided to add the thrust rollers underneath the design at an angle for it to be able to support the entire drive as shown in Figure 44. There are a total of four thrust rollers, each pair is alongside each riding ring.

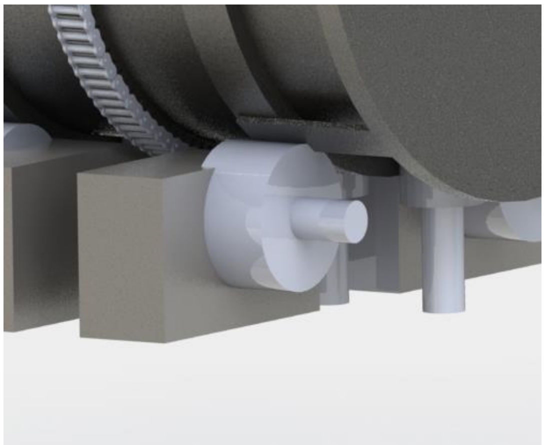


Figure 44: Thrust Rollers

All these purchased components enable the tumbler to rotate safely and reduce the amount of friction. The rotating action components will be secured on a frame which will not be designed under the scope of this project.

4.5 LOADING AND UNLOADING THE STRIPS

Loading and unloading of the strips is an integral part of the design. Our client, McMillan, clearly specified the importance of loading and unloading for our design. As part of the needs, the design must be able to reduce manpower hours and require minimal work. Therefore, the loading and unloading process was designed with lean manufacturing concepts in mind to ensure that the least of manpower is required.

4.5.1 LOADING CAPACITY

To determine the loading capacity of our Tumbler based on its dimensions, we decided to do some research about similar application and their loading ratio comparing to the total capacity of the tumbler. We found that dryers had a similar concept and design, except that moisture is critical in the dryer design but not for our tumbler. Based on the research paper for the design of rotary dryers, the loading capacity ratio for the dryers is between 10 % and 15 % [29].

To find the maximum number of strips that can be loaded into the tumbler this loading capacity ratio was used. The total volume of the internal tumbler was calculated, 15% of this volume will be occupied by the LDPE strips with nickel attached to them.

The tumbler is four feet diameter and five feet in length, the volume was found to be 62.83 ft^3. The strips to be cleaned come in two varying lengths which will be referred to as long and short strips. The dimensions of the long and short strips are respectively: 0.772" x 0.772" x 45"and 0.772" x 0.772" x 30". The volumes of the strips are calculated below:

$$V_{long\ strip} = 26.8193\ in^3 = 0.01552\ ft^3$$

$$V_{short\ strip} = 26.8193\ in^3 = 0.010347\ ft^3$$

Once the volume of the strips are determined, we can find the recommended number of strips to be loaded into the tumbler using 15 % loading ratio:

$$Number\ of\ long\ strips = \frac{15\ \% * 62.83\ ft^3}{0.01552\ ft^3} = 607.24\ strips = 607\ long\ strips$$

$$Number\ of\ short\ strips = \frac{15\ \% * 62.83\ ft^3}{0.010347\ ft^3} = 699.67 strips = 700\ short\ strips$$

The maximum numbers of strips that can be loaded in a single batch using the 15 % loading ratio are found to be 607 long strips or 700 short strips. Tumbler vendors were contacted to ensure the loading capacity used was suitable for our application which is different from rotary dryers. The recommendation for the number of strips to be loaded into the tumbler was 500 strips per batch for safe operation.

4.5.2 LOADING: CHUTE

The entry chute was designed at an angle to allow the LDPE strips to slide into the tumbler. The angle of the tilt was decided to be 15 degrees. This was based on the the minimum angle of tilt for the tumbler that was calculated to be 11.31 degrees, which is the minimum angle needed to ensure the strips slide as covered in Section 4.2.2. Tumbler TiltFigure 45 depicts a rendered image of the entry chute that will be permanently located at the opening of the drum.

Figure 45: Entry chute placed at the opening of the tilted tumbler.

The chute will only allow the entry to the drum, however our team also decided on how to lift and drop the LDPE strips into the chute. To guarantee that this step included the minimum amount of manpower, a tilting forklift will be needed. We were unable to confirm whether the client already has tilting forklifts. However, to ensure that the loading procedure works, we decided to include the cost of purchase of a tilting forklift.

It was determined that the optimum forklift would be a Hyster forklift, model number H8.00XM-6 shown in Figure 46. It also includes a tilting cab for easy service access and to minimize service time and cost [30]. Generally, forklifts can be purchased new or used, however for the purpose of this report; we recommend the purchase of a brand new forklift. Further research lead us to the purchase price of approximately $34,000 [31]. This cost will not be added to our cost analysis because the forklift was determined not an integral part of the design.

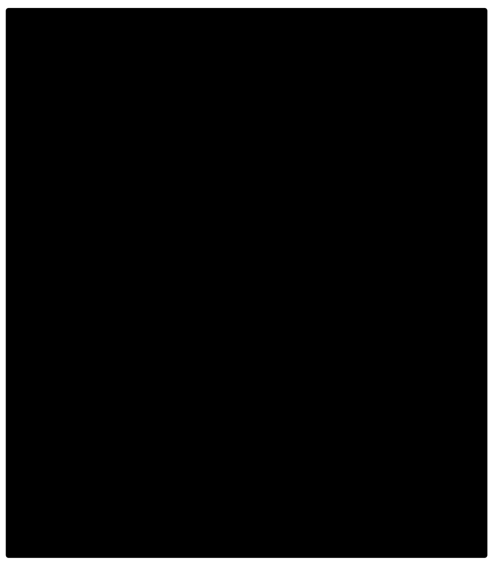


Figure 46: Hyster forklift, model number H8.00XM-6.

Additionally, the purchase of a forklift is only recommended. In the event that Vale already has purchased forklifts that have a tilting mechanism, buying this type of forklift is not required.

As for the process, once the forklift lifts the bin with the LDPE strips and nickel, it also needs to be attached by straps to ensure it does not fall off during the tilt. The full procedure will be explained in the Operator's Philosophy in Appendix C of this report.

4.5.3 UNLOADING: DISCHARGE DOOR

Once the strips are tumbled and the nickel is separated from them, the tumbler design needs to collect the cleaned strips and the nickel separately. This will enable for easy processing of the recovered strips and nickel by reducing the labor required.

Various different designs were developed and available designs were considered for the discharge door. Ultimately, a stationary door which is not attached to the tumbler was decided to be developed. The door will be attached to the support frame and cover for the tyres. The advantages of the stationary door are as follows.

- Easy removal of nickel and strips separately.
- Safe for the operator.
- Minimal manual labor for the operator.
- The door does not rotate; therefore the tumbler can be emptied while it’s rotating without any safety concerns of flying nickel debris.
- Reduces the weight of the tumbler, thereby reducing the power required by the motor to rotate it.

4.5.3.1 MATERIAL

The material for the door was chosen based on the load of the sticks applied due to the tilt angle. The load is much smaller as compared to the actual weight of the nickel and strips, as only the horizontal component will be applicable on the door. Therefore, a lower grade of steel will be a viable option since the environment is highly corrosive. The material selected for the door is structural steel (ASTM-A36). The yield strength of structural steel is 250 MPa with a modulus of elasticity of 200 GPa and the ultimate tensile strength is 400 MPa [13].

4.5.3.2 DIMENSIONS

The dimensions of the door will be crucial in determining its successful operation. The diameter of the door was based on the diameters of the concentric tumblers. The overall diameter of the door will be 1 ft. greater than the bigger tumbler which is five feet to pride complete coverage. Therefore the door diameter will be 6 feet in diameter. The door will consist of two sections, one for the discharge of the separated nickel and the other for the discharge of LDPE strips.

The thickness of the plate was calculated to provide support and sustain its operation under variable loading conditions. The thickness was estimated based on some assumptions for simplicity of the calculations. The results will be verified and optimized by finite element analysis.

The assumptions for the design of the door are as given below.

- The circular door is mounted with loading similar to a simply supported beam.
- The sections and cut outs on the door do not change the properties and the door is considered homogeneous.
- The factor of safety is 5. This is due to the variable loads applied with impact, which is not considered in the simplified calculation.
- The force component acting on the door due to the angle of tilt is considered to be uniformly distributed over the plate.

First the moment of inertia (I) for a circular plate will be found [32]. The radius is converted from feet to meters.

$$I = \frac{\pi \times radius^4}{4} = \frac{\pi \ \times (3 \times 0.3048)^4}{4} = 0.549 \ m^{\ 4}$$

Equation 10: Moment of inertia for a circular plate.

The thickness of the plate should be greater than twice the maximum deflection of the plate under the given loading conditions [33]. The deflection equation will be applied to the plate for a simply supported beam under uniform loading. Before applying the deflection equation the force acting on the door will be calculated. As shown in Figure 47, the force component can be computed. The mass force due to gravity is calculated using the mass of the strips and the nickel in one batch which is 950 kg. The angle of tilt was calculated to be 15° in section 5.1.2.

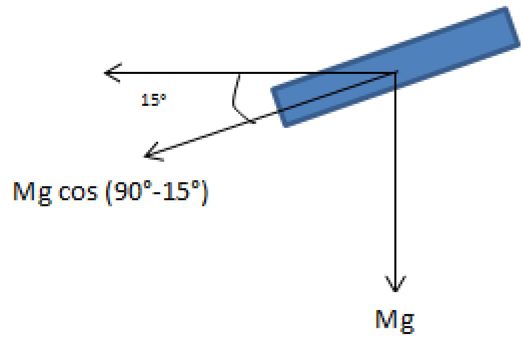


Figure 47: FBD of a LDPE strip with acceleration components

$$Force\ on\ the\ door = 950kg \times 9.81\ m/s^2 \times \cos(90° - 15°) = 2412.51\ \text{N}$$

Maximum deflection (δ) will be found with safety factor applied to the force.

Equation 11: Maximum deflection for a simply supported beam [9].

$$\delta = \frac{PL^3}{48EI} = \frac{2412.51\ \times 5 \times (6 \times 0.3048)^3}{48 \times 200 \times 10^9\ \times 0.549} = 3.57\ \times 10^{-5} m\ or\ 0.0357\ mm$$

The deflection value is found to be 0.0357 mm or 0.0014 inches therefore the thickness of the plate should have a minimum value of twice the deflection value which comes to 0.0714 mm. The load will not be uniform along the plate therefore that will increase the force concentration leading to higher deflection. This value is the minimum therefore in order to reduce bending and account for corrosion allowances this value will need to be considerably higher. The minimum thickness available for A-36 steel plates starts with 3/16 in. or 4.76 mm [34]. This provides us with the thickness of the plate that will be used for the door structure.

The mass of the plate will be found for the supporting structure required.

Density of A-36 = 7860 kg/m^3 [13]

$$Volume\ of\ the\ door = \ \pi \times (3 \times 0.3048)^2 \times (0.00476) = 0.0125m^3$$

$$Mass\ of\ the\ door = 7860\ kg\ \times 0.0125 = 98.28\ kg$$

4.5.3.3 FEATURES

The door will need two separate sections for the removal of nickel and LDPE strips. The section for the nickel removal will be permanently open to allow the nickel to be collected in the wooden bins due to gravity while the bin is rotating. The dimensions of this cut out located at the bottom of the door will be derived from the gap between the two tumblers. The gap is six inches and an additional six inches was cut due to the diameter of the door extended about the external diameter of the tumbler. This will give the vertical dimension of one foot for the section for nickel removal. The horizontal length of the section will be based on the length of the bin available to collect the nickel; it will be about 4 feet. These dimensions stated above are not relative to any origin, the Figure 48 will give a better idea of the door section for nickel removal.

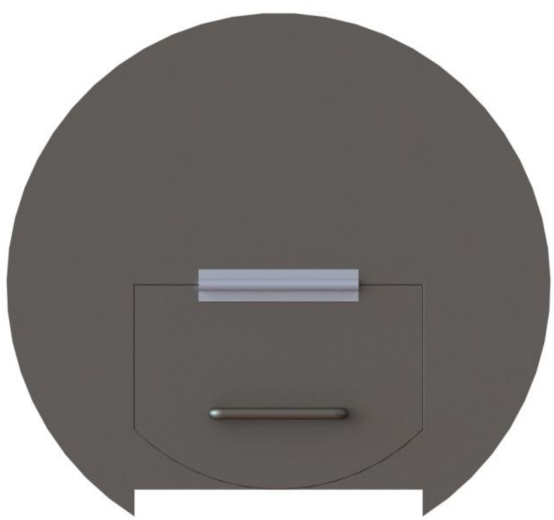


Figure 48: The discharge door

The section for the removal of the strips will be a door that can be locked while the removal is in process. Once all the nickel from a single batch is separated and collected in a bin, the nickel bin is replaced with another bin for to collect the cleaned LDPE strips. The door dimensions are based on the diameter of the inside tumbler in a semi-circular shape. The hinged door will open upwards to allow discharge of the LDPE strips due to gravity and the rotating action of the tumbler. The hinge was selected based on the load, size of the door, material of the door, door mass and clearance allowed between the door and frame. The values are given below.

- Load on the door (F.S. =5) =12060 N
- Size of the door (Semi-circle)
    - Radius = 2 feet or 0.61 m (approximate value, clearance will be subtracted)
    - Thickness = 3/16 inches or 4.76 m
- Material = Structural steel, A-36
- Mass of door (density x volume) = 43.68 Kg
- Clearance = 0.6 inches or 15 mm

The door will be required to be unlocked and lifted upwards to allow the strips to fall out. Since the mass of the door to be lifted is about 44 kg, therefore it poses a safety risk for the operator and makes it labor intensive as well. In order to mitigate the risk and make the process easier for the operator a motorized monorail hoist will be attached to the available I-beam rail in the nickel removal area (Figure 49). The hook from hoist chain will be inserted in the handle and stay in it permanently. When the strips need to be recovered from the tumbler the operator can lift the door by operating the hoist. The operators will need to be trained on the hoist operation.

Figure 49: Overhead rail in the nickel cleaning area

The hoist selected for lifting the door was a ½ ton monorail hoist. It can be purchased from Yale and the model is Global King Monorail, the price of the hoist is about CAS $ 4582.

4.6 ROTATIONAL SPEED

The rotational speed of the tumbler was calculated by ensuring the LDPE strips fall freely and collide with the surface of the tumbler. This was done by considering the centripetal force and the mass of the force on the strips due to gravity. The centripetal force cannot be greater than gravitational force or else the strips will not fall freely during the rotation of the tumbler. This scenario will not remove nickel as no impact force will act on the strip. This analysis considered one long strip for simplification, as the velocity required by one strip is equal to the velocity required by 500 strips for the free fall to occur. We will start the calculations using the mentioned principle to find the rotational speed of the tumbler.

Reiterating the principle, $F_c < F_g$. Where:

- F_c is the centripetal force
- F_g is the force of gravity

The relationship between F_c and the linear velocity is presented in the following equation:

$$F_c = \frac{m * v^2}{r}$$

Equation 12: Centripetal force

Where:

- m is the mass of the strip.
- v is the linear velocity of the strip.
- r is the radius of the tumbler.

The relationship between F_g and the gravity is presented in the following equation:

$$F_g = m * g$$

Equation 13: Gravitational force

Where:

- m is the mass of the strip.

- g is the gravitational acceleration.

Using the three previous equations, we get the following equation:

$$\frac{m * v^2}{r} < m * g$$

After rearranging the equation to find the linear velocity, we find:

$$v < \sqrt{g * r}$$

After plugging the following values of r, the radius of the tumbler, which is 2 feet or 0.6096 m and g, the gravitational acceleration which is 9.81 m/s^{2}, we find:

$$v < \sqrt{9.81 * 0.6096}$$

$$v < 2.45 \text{ m/s}$$

The maximum linear velocity of the strips is 2.45 m/s. We assume that the sticks and the tumbler have the same velocity since they are part of the same system, so we can find the rotational speed of the tumbler using the following equation:

$$\omega_{max} = \frac{v}{r}$$

Equation 14: Maximum angular velocity

Where:

- ω is the rotational speed of the tumbler.
- r is the radius of the tumbler.

After plugging in our values, we get:

$$\omega_{max} = \frac{2.45}{0.6096}$$

$$\omega_{max} = 4.02\ rad/s$$

We found the maximum rotational speed of the tumbler in radians per seconds but it is more useful to convert it in revolutions per minute:

$$\omega_{max} = 4.0 \frac{rad}{s} * \frac{60}{\pi} * \frac{s * rev}{min * rad}$$

$$\omega_{max} = 38.38 \frac{rev}{min}$$

The maximum rotational speed of the tumbler is 38.38 revolutions per minute.

Once the maximum allowable rotational speed of the tumbler was found the range of force calculated in section 4.5 was used to find the optimal rotational speed. The range of force required for the nickel removal process is between 10 N and 100 N.

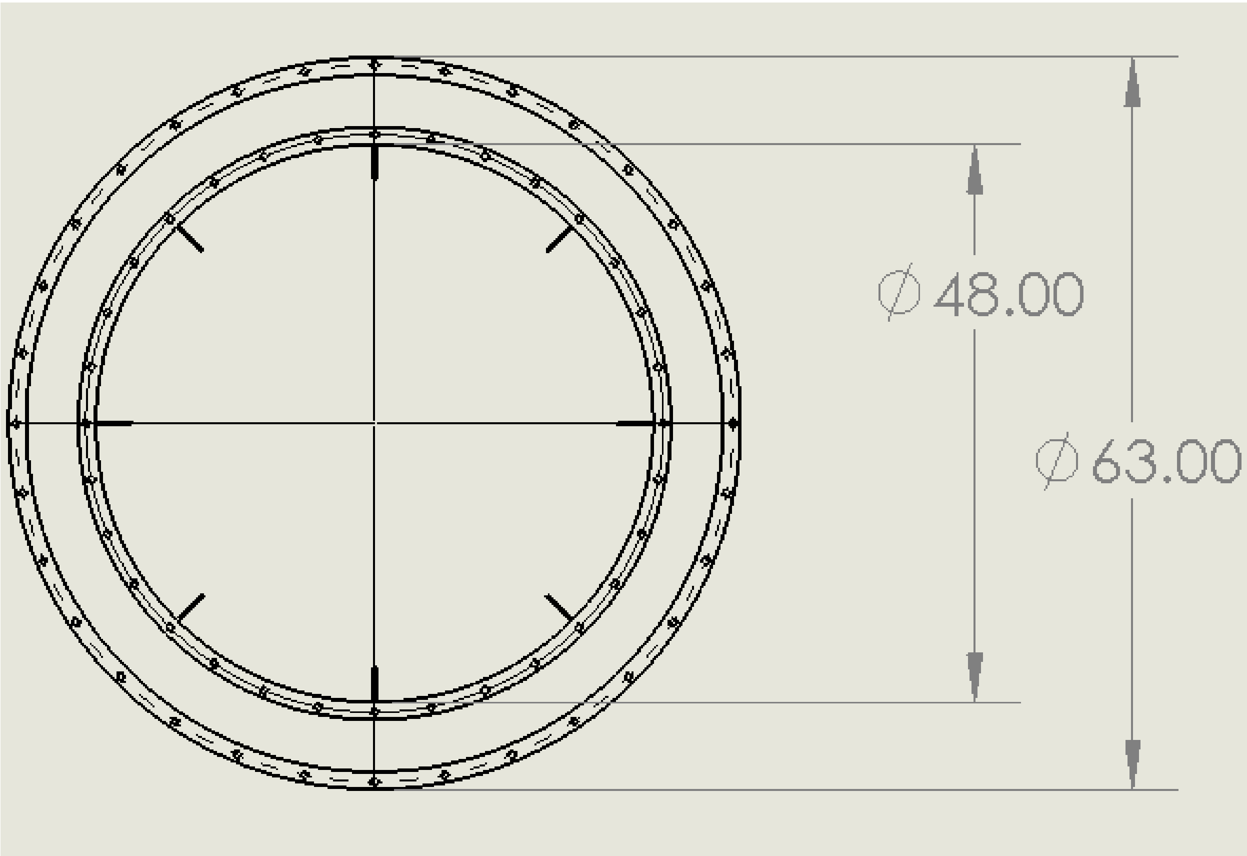


Figure 50: Drum sketch presenting the relevant dimensions for our analysis

The strip falls twice from the top point of the tumbler in one revolution. As we can see in Figure 50, the inner diameter of the tumbler is 4 feet or 48 inches then we can find the gravitational force exerted by the mass of the strip. Prior to that we need to find the mass of the long strip which was found based on the density provided by the manufacturer and the volume calculated. The mass of the strip was found to be 0.4 Kg.

In order to find the gravitational force exerted by the weight of the strip Equation 13 was used and the force was found to be 3.92 N.

Since in one revolution, the strip falls twice than the force 3.92 N is applied twice, so the total force applied in 1 revolution can be found using the following equation:

$$F_{total} = F_{fall} * 2$$

Equation 15: Total force per one revolution applied to the strip

Where:

- F_{total} is the total force applied to the stick in one revolutions.
- F_{fall} is the force applied to the stick in one fall or half a revolution.

After plugging our numbers, we get:

$$F_{total} = 3.92 * 2 = 7.85\ N$$

Since the required force to remove the nickel from the strips was found to be from 5 to 100 N, to be conservative, we select the highest force which is 100 N. A table showing iterations performed in appendix B-7 was used to get the optimal value for a100 N force was found to be between 12 and 13 revolutions per minute. After interpolating this value, the rotational speed was found to be 12.67 revolutions per minute to get a cumulative force of 100 N applied to the stick. Cumulative forces applied to the stick in one minute from 0 to 38 revolutions per minute, since the rotational speed of the tumbler cannot exceed 38.38 revolutions per minute.

4.7 FINITE ELEMENT ANALYSIS

In this section, we will discuss the stress effect of the strips and the nickel attached to them during the rotation of the tumbler. We used finite element analysis to evaluate the stress in the tumbler caused by the strips and the nickel attached to them. This is a preliminary finite element analysis performed by student and the results can vary as the level of experience is low. The results should not be considered final and should be verified by a professional prior to manufacturing.

We know that the weight of the long strip is 0.4 kg and we assumed that the weight of the nickel attached to the strips is 1.5 kg, so the total mass per strip is 1.9 kg. The total mass of 500 strips will be 950 kg. The force of gravity caused by the mass of the 500 strips on the tumbler was found to be 9319.4 using Equation 13.

After finding the primary force acting on the tumbler, we will talk about the boundary conditions. The boundary conditions of our finite element analysis are represented in Figure 51 and Figure 52.

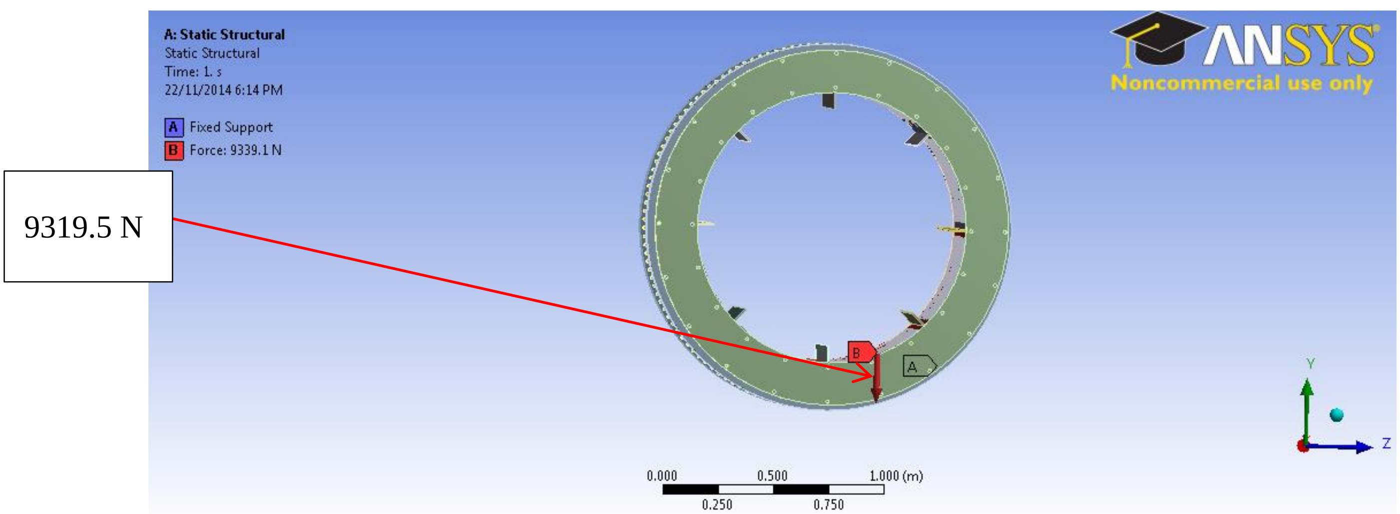


Figure 51: Force applied to the tumbler represented by ' B '.

The finite element analysis was done on stationary tumbler system and the load of 500 strips acts on the lower half of the tumbler as seen in Figure 52.The support of the tumbler is assumed to be fixed since the analysis is stationary as we can see in Figure 52.

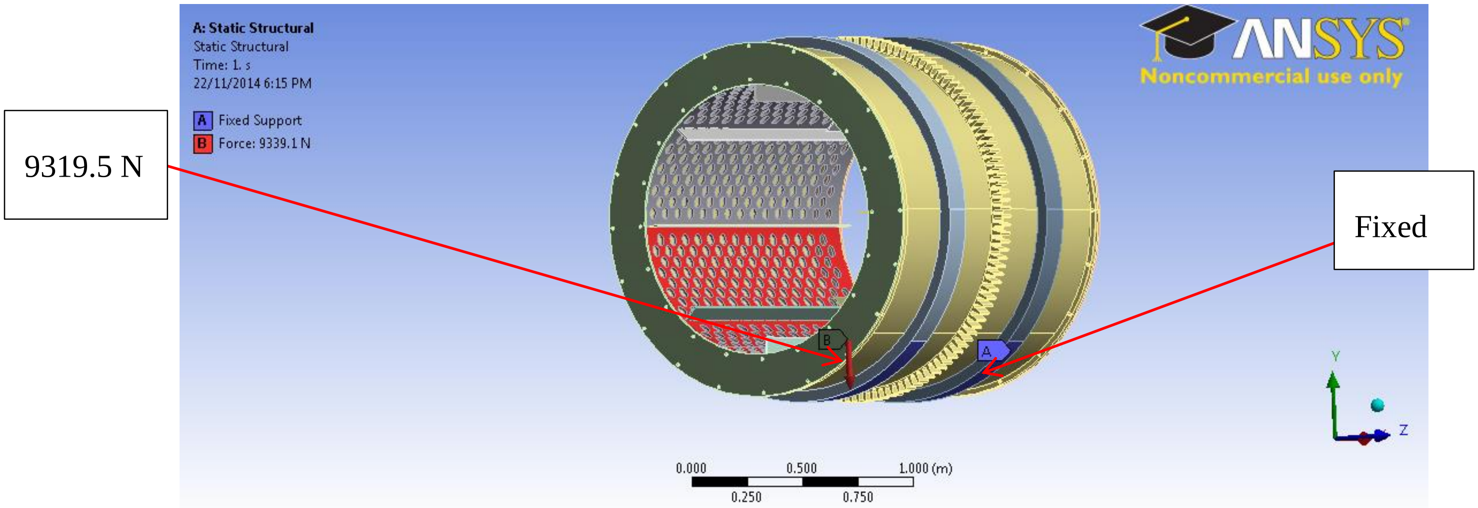


Figure 52: Fixed support of the tumbler represented by ' A'.

After performing different meshes on the tumbler and creating a meshing convergence curve to identify the best mesh for this study, we obtained a mesh size of 8 mm as we can see in the following figure.

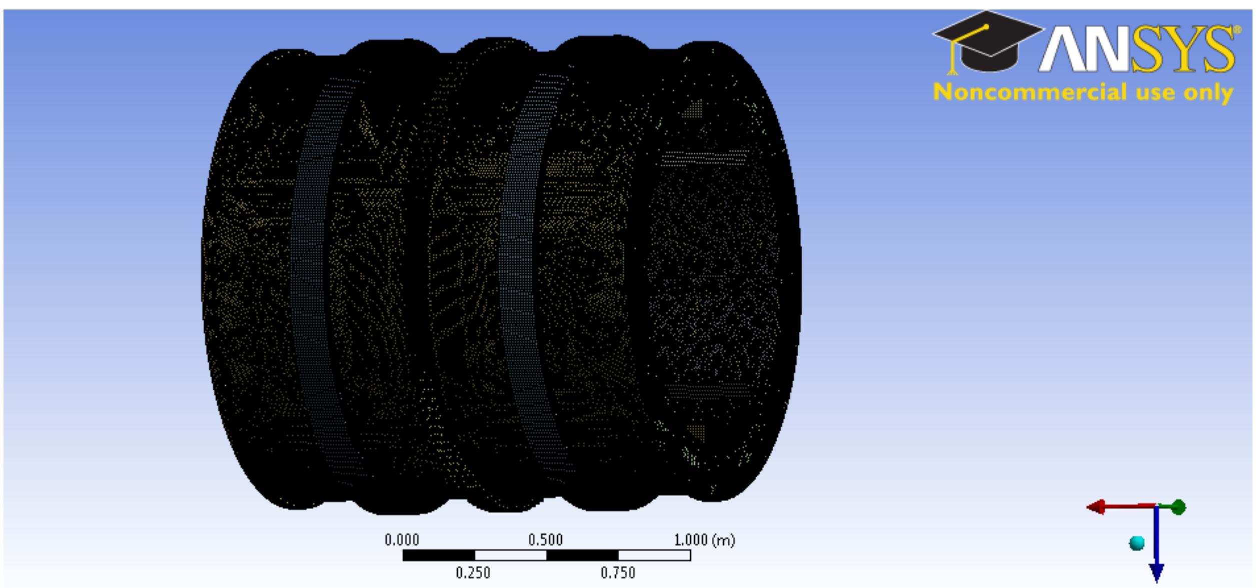


Figure 53 : Meshed tumbler using a mesh size of 8 mm.

After finding the ideal mesh and meshing the tumbler, we performed our finite element analysis considering the Von Mises stresses, total deformation and safety factors as we can see in Figure 54, Figure 55, Figure 56, Figure 57 and Figure 58.

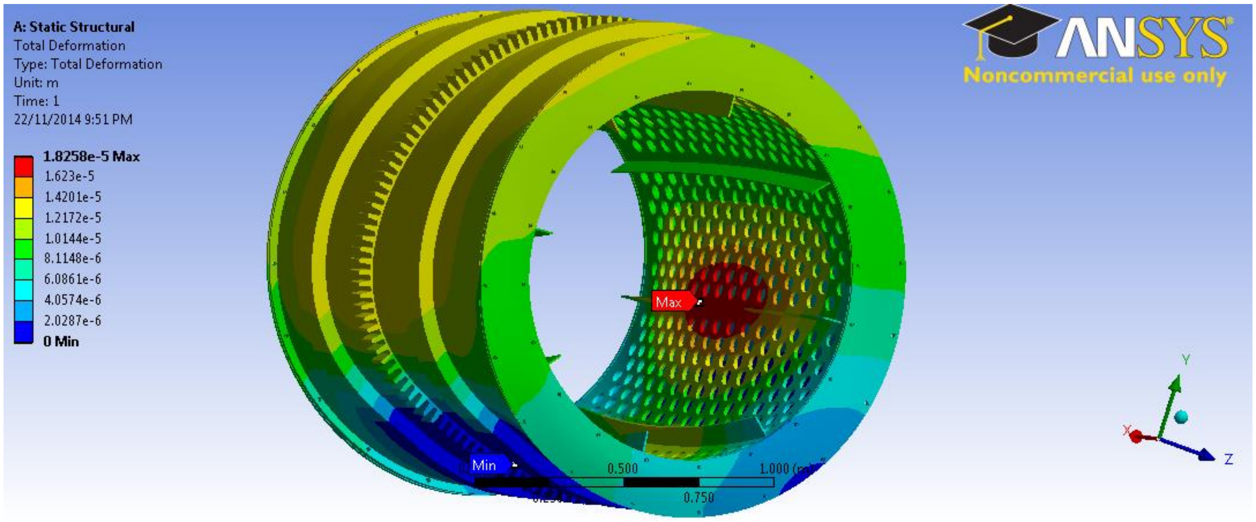


Figure 54: Total deformation of the tumbler.

In Figure 54, we can see that the total deformation of the tumbler varies from 0 m to 0.0182 mm which is a very low deformation of the tumbler keeping in mind that this is an approximation of the deformation based on the volume of the model. We can notice that the effect of the 500 strips with the nickel is very minimal on the tumbler.

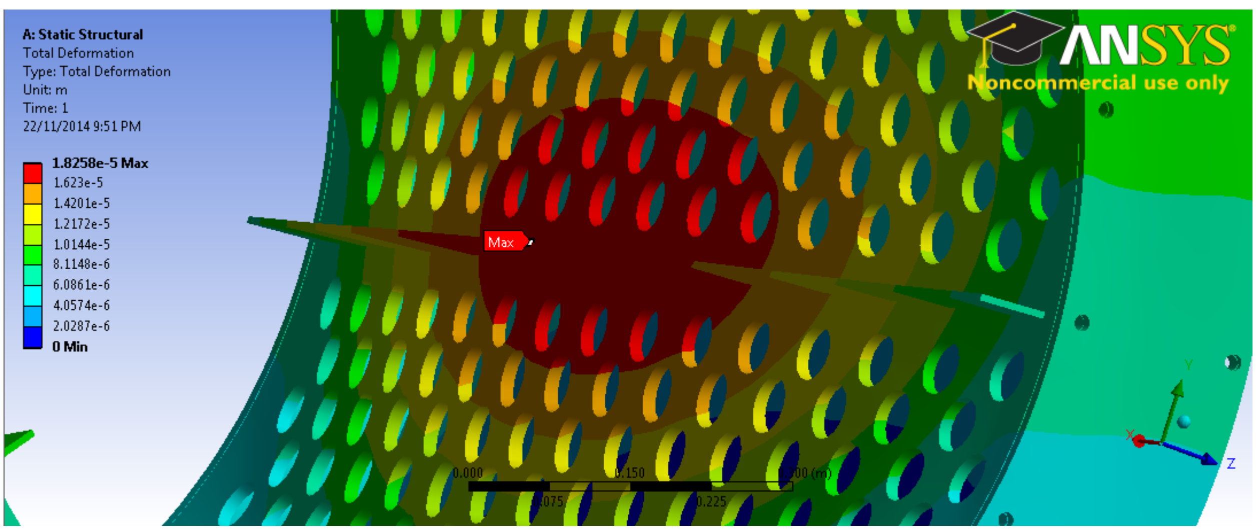


Figure 55: Closer view of the maximum total deformation of the tumbler.

In Figure 55, we can see that the maximum deflection is at the assumed fixed support of the tumbler which is about 0.018258 mm.

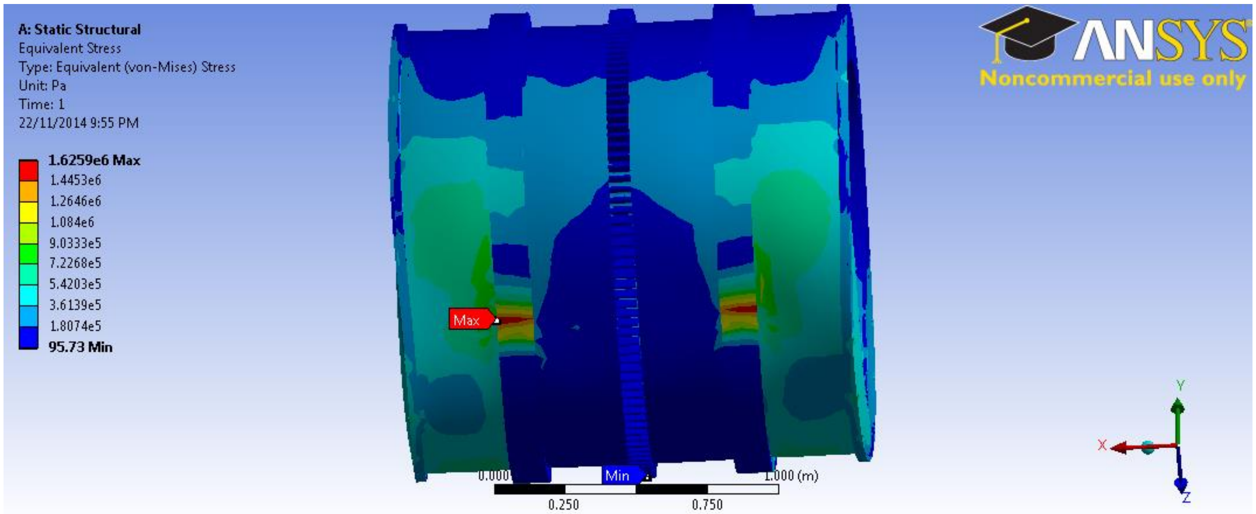


Figure 56: Von Mises stresses of the tumbler.

In Figure 56, we can see that the maximum Von Mises Stress is at the fixed support of the tumbler which is about 1.63 MPa. The ultimate stress of the 316 stainless steel is 860 MPa; the maximum stress of the tumbler is less than 1 % of the ultimate stress of the 316 stainless steel.

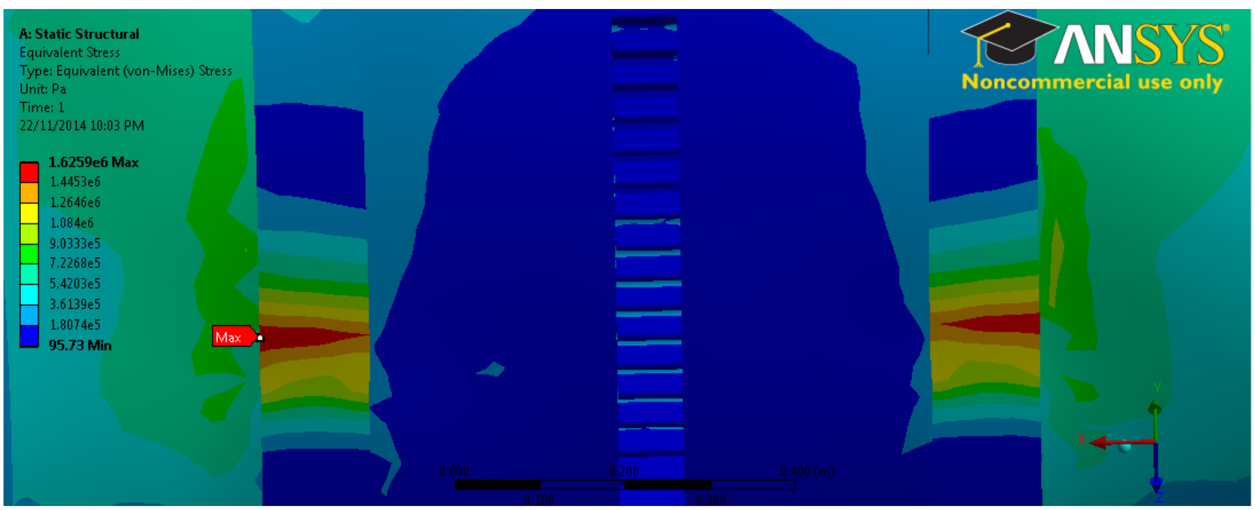


Figure 57: Closer view of the maximum Von Mises stress of the tumbler.

In Figure 57, we can see a closer view of the maximum Von Mises stress which is exactly at the contact point between the fixed support and the tumbler. This indicates of our analysis is logical since by theory the maximum stress is supposed to be at the fixed support of a design.

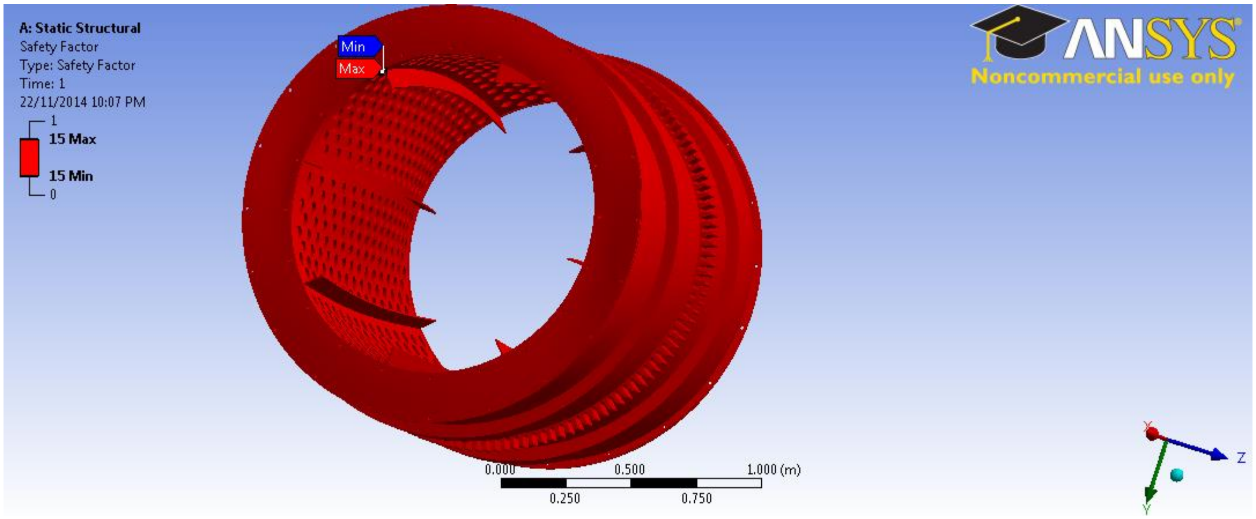


Figure 58: Safety factor of the tumbler.

In Figure 58, the safety factor of the tumbler during the application is 15, which is the maximum safety factor that we can get.

In conclusion, the effect of the force caused by the 500 long strips is extremely minimal on the tumbler effect based on the finite element analysis. The tumbler design can be optimized to reduce cost whereas the safety will be compromised by a certain amount. Following the client's recommendation and our engineering intuition that safety of the public is the number one priority.

After analyzing the effect of the 500 long strips with the nickel on the tilted tumbler, we now analyze the effect of the load of 500 long strips with the nickel on the door. The force of 2500 N was found based on the calculations mentioned in section 5.4.3.

We can see the effect of the force using the finite element analysis method in Figure 59, Figure 60, Figure 61 and Figure 62, the total deformation, the Von Mises stresses and the safety factor were considered.

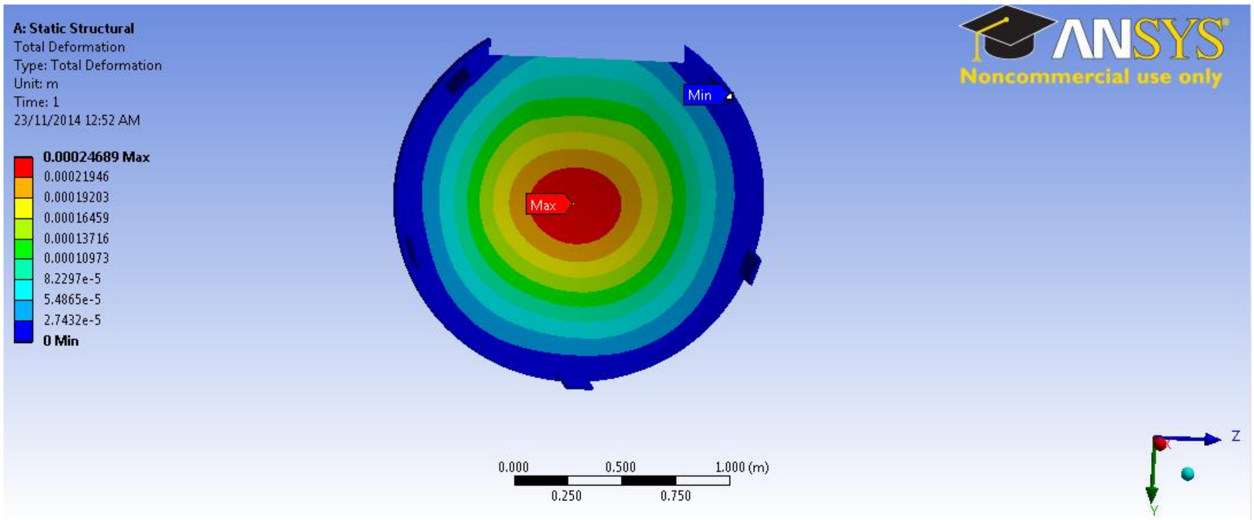


Figure 59: Total deformation applied to the door assuming a force of 2500 N

The maximum estimated total deformation is 0. 247 mm when the force of 2500 N is applied, as shown in Figure 59 the maximum deflection is at the center of the door due to the presence of the hinge at that location.

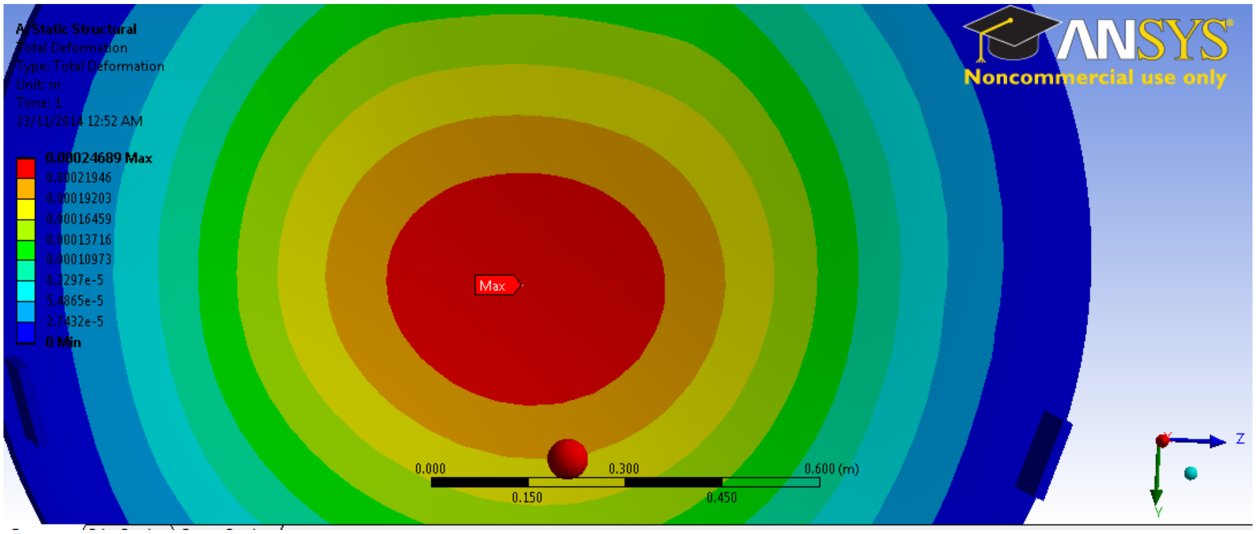


Figure 60 : Closer view of the maximum total deformation with the force applied to the door.

In a closer view of the maximum deflection in Figure 60, the maximum deflection decreases as the radius increases. The maximum deflection is minimal and we can say that the force has a minimal effect on the door.

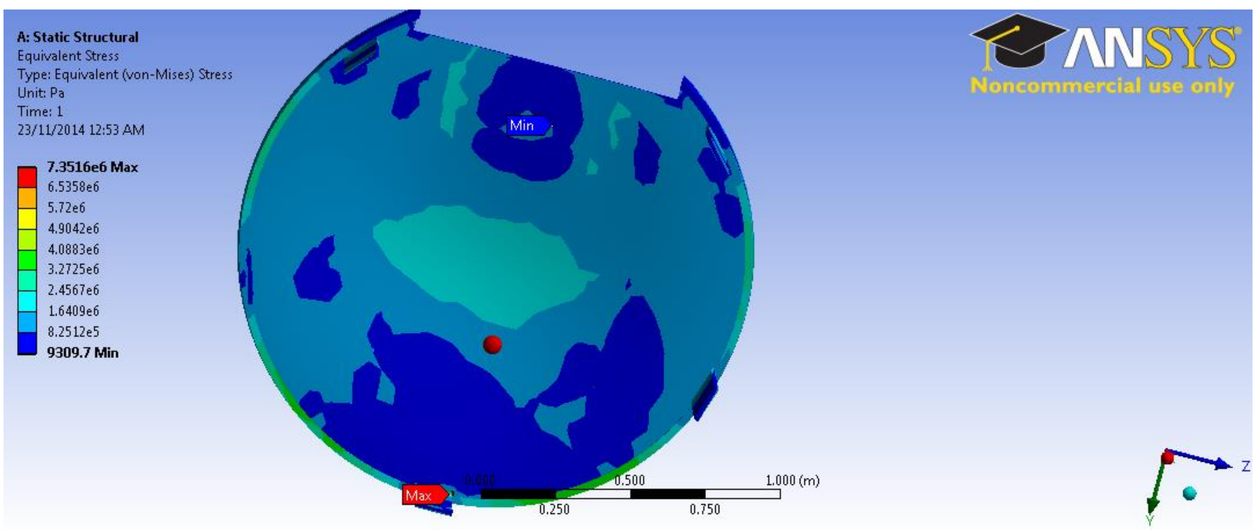


Figure 61: Von Mises stresses with a force of 2500 N applied to the door.

In Figure 62, we can see the distribution of the Von Mises stresses when the same force of 2500 N is applied to the door. The maximum stress is 0.735 MPa which is extremely small and less than one percent of the yield strength which is 235 MPa.

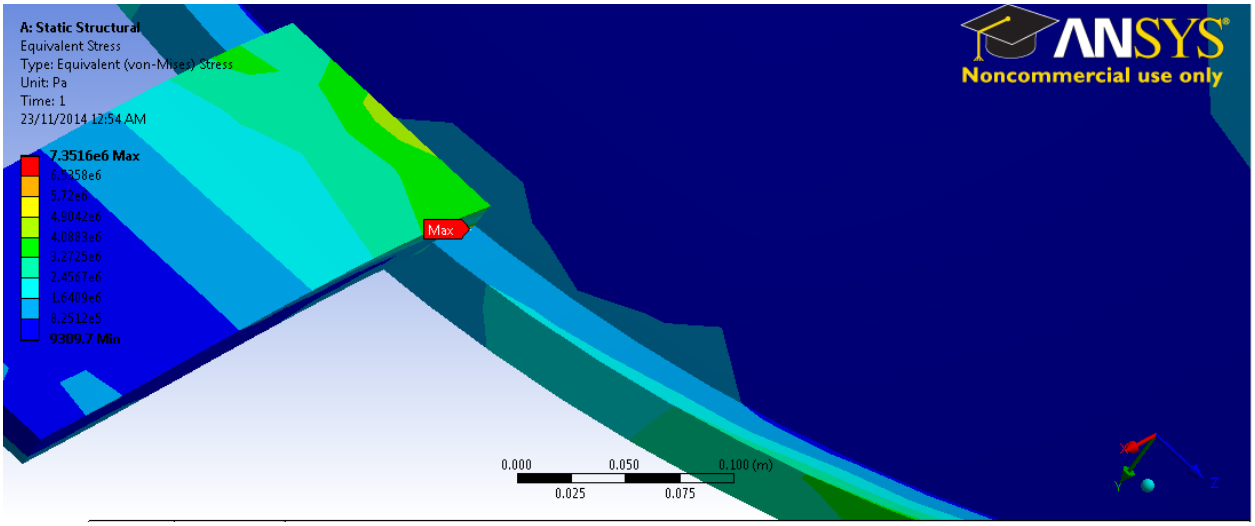


Figure 62 : Closer view of the maximum stress of the door when the force of 2500 N is being applied.

In Figure 62, the maximum deflection of the stress is shown at the welded support of the fixed door connected to the tumbler frame. The maximum stress should be in that location by theory since the support is fixed.

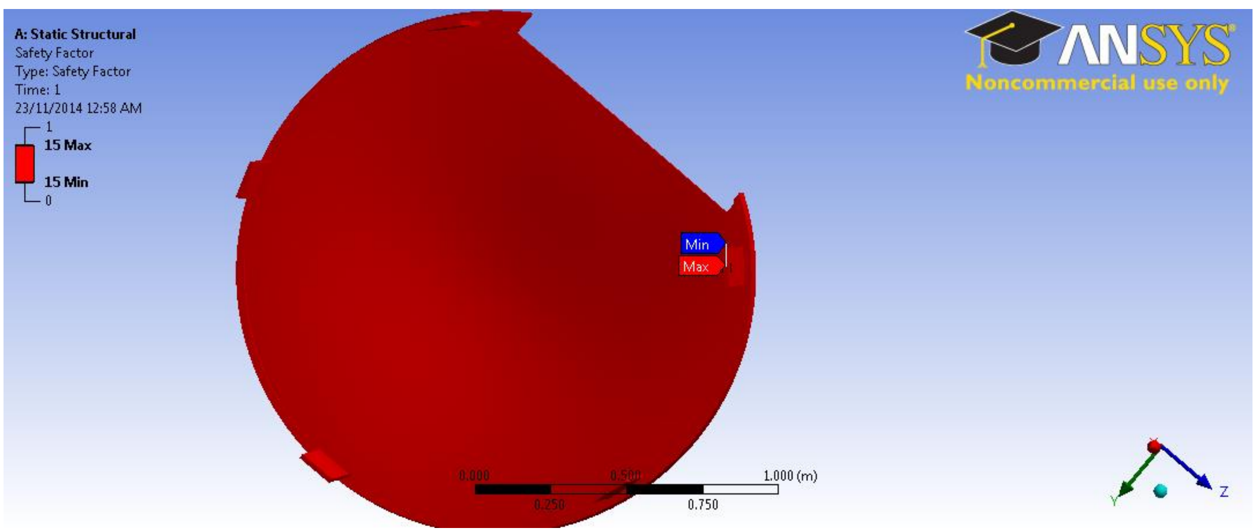


Figure 63: Safety factor of the door when a force of 2500 N is applied.

In Figure 63, the factor of safety is 15, where the minimum allowable safety factor of 2 is required for a safe design for most applications. A high safety factor means that the design can be optimized to reduce the cost similar to the design of the tumbler, we considered safety over cost for our design.

In conclusion, we analyzed the force of the 500 long strips and realized that there is a minimal effect on the door based on the total deformation, Von Mises stress and safety factor.

4.8 FAILURE MODES AND EFFECTS ANALYSIS

Failure modes and effects analysis is a structured approach to identifying the ways in which a product or process can fail. Failure mode effect and analysis is usually summarized in a form of a table where the product and processes are identified along with their potential failure mode, its potential effect, current controls and the action recommendations.

The failure modes and effects analysis completed for our design was completed by the team during a brainstorming session where we began by separating the major components of the tilted tumbler system shown in Figure 11. The FMEA can be used to develop a preventative maintenance plan for the tumbler system. The plan can be improved further once the system is in operation and its critical components can be identified with data of performance. The FMEA for the tumbler system is shown in TABLE XXXI.

TABLE XXXI: FMEA FOR THE TILTED TUMBLER DESIGN

Failure modes and effects analysis (FMEA)

Project:	**Starter Strip Nickel Removal Process Design**	Sponsor	**Vale**
FMEA Team:	Team 19 - University of Manitoba Mining Team	Prepared by:	Design Team

SEV = How severe is effect on the customer?
OCC = How frequent is the cause likely to occur?
DET = How probable is detection of cause?
RPN = Risk priority number in order to rank concerns; calculated as SEV x OCC x DET

Process step	Potential failure mode	Potential failure effects	SEV	Potential causes	OCC	Current process controls	DET	RPN	Actions recommended
Loading strips	Loading strips to a higher capacity	External support from roller support fails.	10		1	Operator’s philosophy to ensure correct loading.	2	**20**	Following the operator's philosophy -Proper training for operators -Periodic refresher training
		External support from the thrust rollers fails.	10	Inexperience of the operator Reducing the process time	1	abnormal noise from the motor	4	**40**	Preventative Maintenance
		Drive system does not run due to the excessive weight	7		1	Visual inspection	8	**56**	Checking Wear on the chain links
		Attachment to the tyre breaks for the discharge door.	8		1	preventative maintenance	1	**8**	
		Bolts break.	7		2	visual inspection	4	**56**	
	Loading strips to smaller capacity	Less amounts of nickel removed Unplanned delays	3	Inexperience of the operator Insufficient equipment availability	6	Operator’s philosophy to ensure correct loading. Availability of equipment to the designated area (Forklift etc.)	6	**108**	
	Batch has a higher amount of nickel	Drive system does not run due to the excessive weight	7		1	Visual inspection	8	**56**	Checking Wear on the chain links
		External support from the thrust rollers fails.	10		1	abnormal noise from the motor	4	40	Preventative Maintenance
		External support from roller support fails.	10	Plating process is ineffective Bin not filled as per recommendation	1	High factors of safety in the design	4	**40**	Preventative Maintenance
		Attachment to the tyre breaks for the discharge door.	8		1	High factors of safety in the design	1	**8**	
		Bolts break.	7		2	Visual inspection	4	56	
		Attachment to the tyre breaks for the discharge door.	8		1	Preventative maintenance	1	8	
	Operator unware where to load the strips	Halted Process Damage to chute or tumbler Potential safety risks for operator	10	Inexperience of the operator	2	Operator's philosophy	1	**20**	Following the operator's philosophy -Proper training for operators -Periodic refresher training

Unloading strips	Door lock stuck	Unable to recover cleaned strips	6	Mechanical failure Strips or nickel stuck in the opening overload from sticks	8	Minimal clearance between door and frame Routine Cleaning	1	**48**	Preventative maintenance Availability of spares locks
		Halted Process	10		2		1	**20**	
		Damage to the door	6		2		1	**12**	
	Injury from nickel	Lost time	10	Lack of training Improper training Faulty design	6	Lifting door with a hoist operator's philosophy PPE Hoist operation training	1	**60**	Proper training procedures Proper PPE for designated areas Following Operator's philosophy accurately
		Health Costs	1		6		1	**6**	
		Harm to reputation	9		6		1	**54**	
		Risk to employee safety	10		6		8	**480**	
	Hoist non-operational	Risk to employee safety	10	Faulty design No maintenance Improper use	2		1	**20**	Spares updated training procedures Periodic refresher training Semi-annual inspections
		halted process	10		2		1	**20**	
	Strips do not exit on rotating	Presence of impurities in the tumbler	6		2		2	**24**	
	Damage to door	Safety hazards	6	Overload High Impact Stress Concentration fatigue	6	Visual Inspection	7	252	g
Nickel removal	Rotation of tumbler inoperable	Motor failure	10	Overload on the motor Voltage Fluctuation Physical damage to motor Power Cuts	2	Visual inspection Preventative maintenance	7	**140**	Using Fuse Back up power source Infrared testing
		Thrust Roller Failure	10	Excessive wear Cracks Misalignment with tyre Bearing Failure	5	Visual inspection	6	**300**	Spares
		Support failure	10	Stress concentration Excessive loading Fatigue	1	Visual inspection Preventative maintenance	3	**30**	Annual ultrasonic testing
		Chain drive failure	10	Chain link wear Stretching of the chain	5	Preventative maintenance Lubrication	7	**350**	Use tension meter to check chain tension Spares
		Shaft failure	10	Wear Overload Stress concentration Bending	3	Visual inspection	8	**240**	Spares
		Key failure	10	Wear Stress concentration Debris getting stuck between shaft and key	1	Visual inspection	9	**90**	Spares
		Sprocket teeth failure	10	Wear overload	3	Visual inspection Preventative maintenance	8	**240**	Spares
		Tyre failure	10	Wear misalignment	1	Visual inspection Preventative maintenance	4	40	ultrasonic testing annually
		Tumbler Failure	10	Wear Fatigue Crack growth	1	visual inspection	8	80	Ultrasonic testing Welding inspections

4.9 FINAL DESIGN

All the components described which contain designed and purchased components comprise to form the final Tilted Tumbler System. The designed components include the concentric tumblers, the discharge door and the entry chute. The purchased components that were decided based on the specifications were the transmission system, external supports, the hoist and the nuts and bolts. The design meets the customer needs and constraints. The final design is shown in Figure 64 and Figure 65.

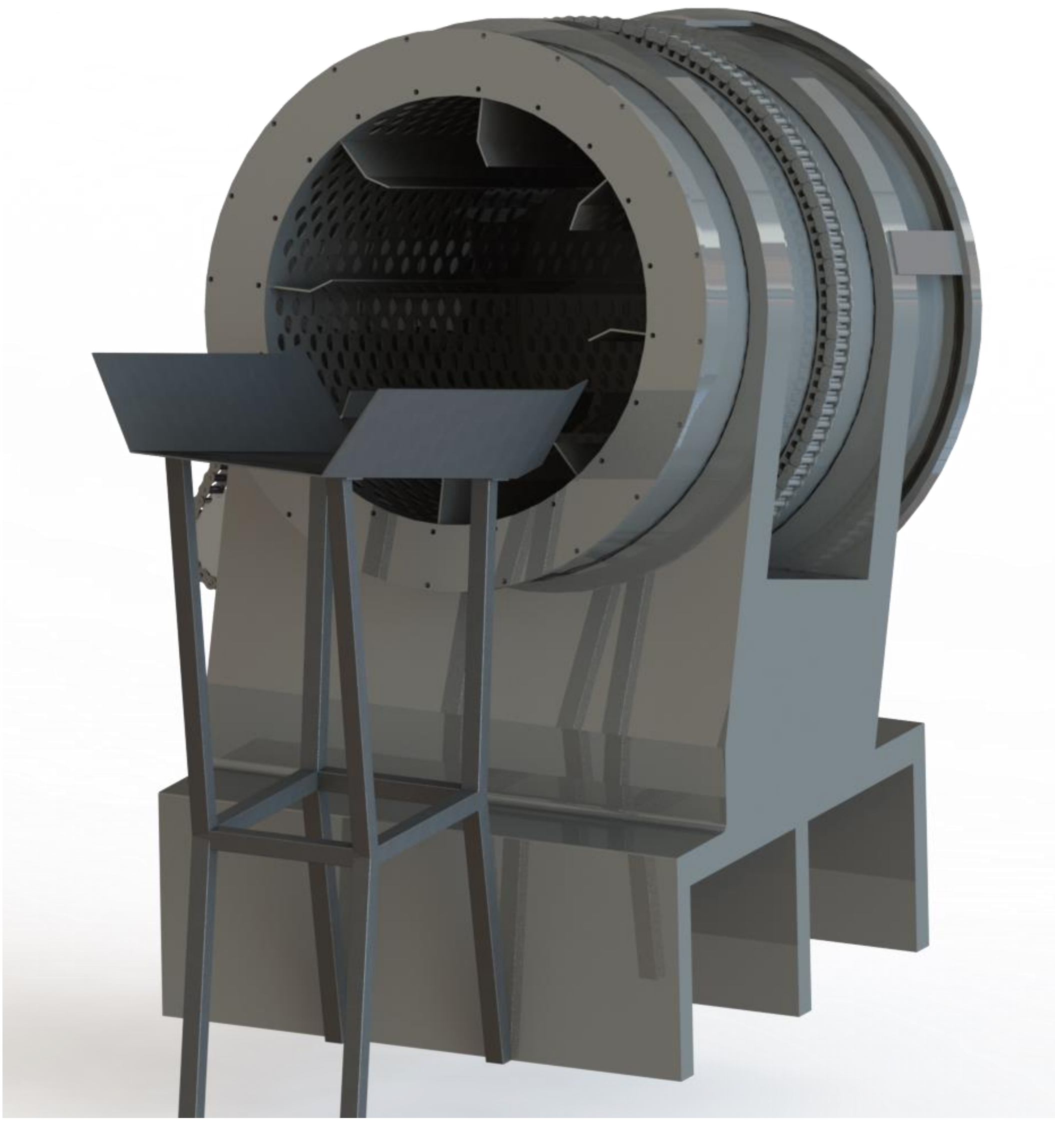


Figure 64: The final Tilted Tumbler System, view of the LDPE strips inlet section

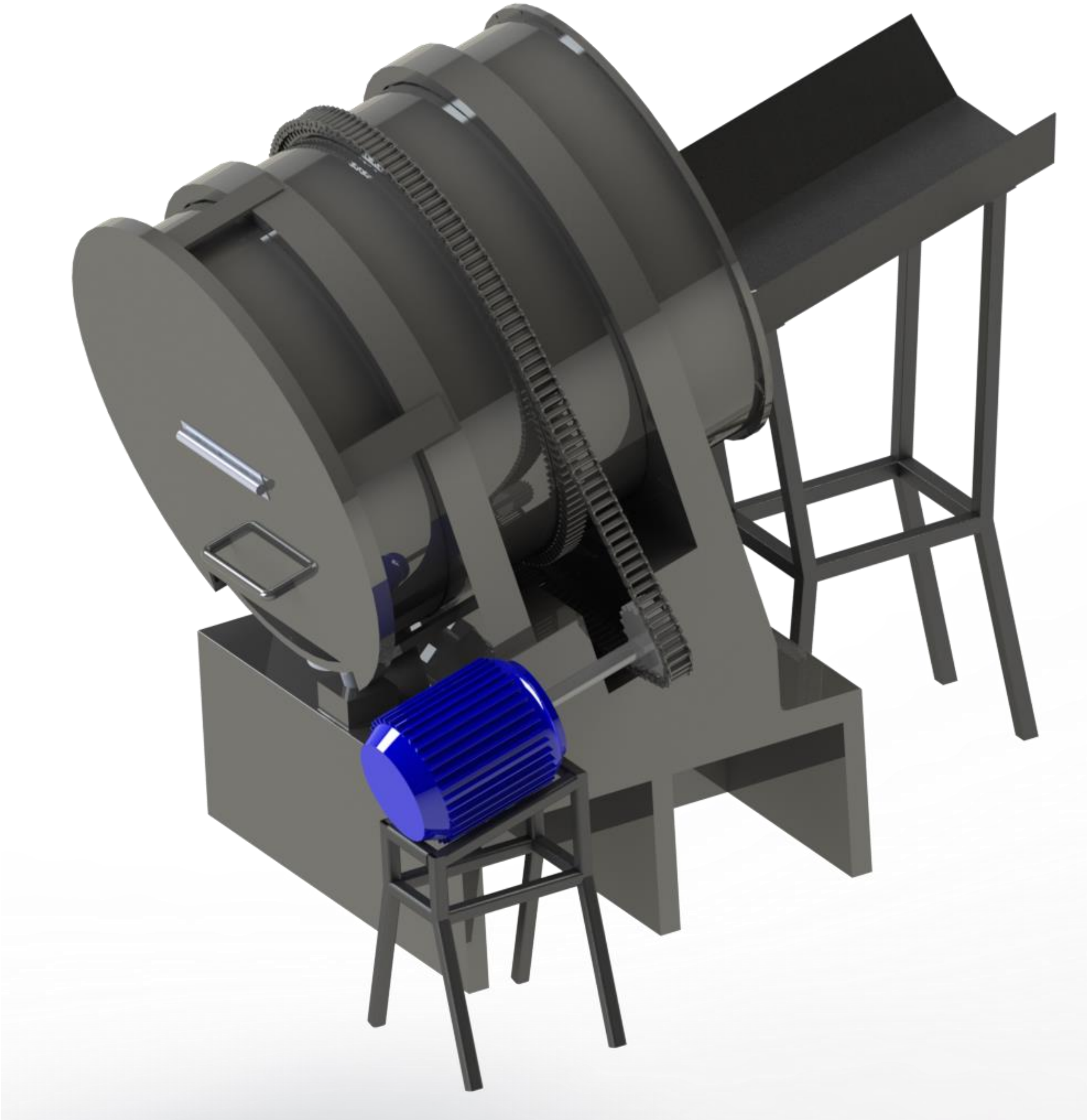


Figure 65: The final Tilted Tumbler System, side view

4.10 COST ANALYSIS

The cost analysis was completed based on two types of costs: capital costs and maintenance costs. The capital costs are summarized in TABLE XXXII. For the capital costs, some components are custom-made which is why the cost of the raw material was taken into account and manufacturing costs were determined to be approximately $9/lb. A

TABLE XXXII: CAPITAL COSTS FOR THE TILTED TUMBLER SYSTEM

Capital Costs					Type of cost		
		Material ($)			Purchase ($)		
		Quantity (lbs)	Cost	Total cost	Quantity	Cost	Total cost
Tumbling cylinder	**Outer cylinder**	960	1.5325	1471.2	N/A	N/A	N/A
	Inner cylinder	660	1.5325	1011.45	N/A	N/A	N/A
	Radial plates	104	1.5325	159.38	N/A	N/A	N/A
	Connector plate	92	1.5325	140.99	N/A	N/A	N/A
Drive system	**Number 120 Chain**	N/A	N/A	N/A	25 feet	28.34	708.50
	Driven sprocket	N/A	N/A	N/A	1	263.25	263.25
	Driving sprocket	N/A	N/A	N/A	1	1888.23	1888.23
	Shaft	N/A	N/A	N/A	1	2998.00	2998.00
	Keys	N/A	N/A	N/A			
	Motor and reducer	N/A	N/A	N/A			
Exit door	**Hoist motor**	N/A	N/A	N/A	1	4582	4582
	Hoist chains	N/A	N/A	N/A			
	Discharge door	612	0.273	167.076	N/A	N/A	N/A
External support	**Roller support**	N/A	N/A	N/A	2	28,000	56000.00
	Riding rings	N/A	N/A	N/A			
	Thrust rollers	N/A	N/A	N/A			
Fabrication	**All components**	2428	9	21852	N/A	N/A	N/A
Total				24802.10			66439.98
						Total	**91242.08**

The maintenance costs are presented in TABLE XXXIII. The only maintenance costs determined were for the lubrication required on the chains and sprockets. Also, when the system is in place, there will be a laborer unloading and offloading the starter strips. We calculated that the unloading and offloading time per day is approximately 3.5 hours which is a very conservative value.

TABLE XXXIII: MAINTENANCE COSTS

Maintenance costs		Unit	Total cost
Equipment	Chain lubrication	$15/month	180
Labour costs		910 hours/year	81,900
		Total	**$82080**

4.11 PAYBACK SCHEDULE

After finding the capital cost of our design and the operating cost, we had to find the operating cost of the current whacking system to be able to create the payback schedule. The current labourer cost are approximately $90/hr, he works 8 hours per day and 5 days a week so the total operating cost of the current system is $187,200. There is no capital cost for the current nickel removal system.

TABLE XXXIV: SUMMARY OF DESIGN IMPLEMENTATION'S MAJOR COSTS

Capital Cost	**$91,242.08**
Operating Cost	$82,000.00
Operating Cost of Current System	$187,200.00
Saving Per Year	$105,200.00

We are going to create, two payback schedules for our design, the first one will ignore the inflation effect of the cash flows while the second one will consider the inflation effect with an inflation rate of 1.9 %.

4.11.1 NO INFLATION

The total cost saving of our design comparing to the current system at the end of a time period of 3 years without considering the inflation effect is $224,357.92. Unfortunately, a payback schedule without the inflation considered is not accurate. TABLE XXXV lists the cash flow at the end of every year once the design has been implemented.

TABLE XXXV: PAYBACK SCHEDULE WITH NO INFLATION

Years	Cash flow
0	-$91,242.08
1	$13,957.92
2	$119,157.92
3	$224,357.92

A final cash flow of $224,357.92 is extremely beneficial for the company and at this point, the Tilted Tumbler System is highly recommended for fabrication.

4.11.2 INFLATION CONSIDERED

The total cost saving of our design comparing to the current system at the end of a time period of 3 years including an inflation rate of 1.9% is $133,877.16. TABLE XXXVI demonstrates the cash flow at the end of every year when inflation is taken into account.

TABLE XXXVI: PAYBACK SCHEDULE WITH INFLATION

Years	Cash flow
0	-$91,242.08
1	-$2,838.72
2	$71,449.82
3	$133,877.16

Additionally, this table is a more accurate representation of when the company will break even with inflation. As per the results of our payback investment analysis, the operation of the tilted system will allow the company to produce profits between year 1 and year 2. As the time allotted for investment payback was deemed as three years by the client, these calculations prove that our Tilted Tumbler System meets the cost criteria.

5 PURCHASING OPTIONS

The major components of the tilted tumbler were designed by the team. The design was based on effective engineering calculations carried out for individual components. However, in order to calculate various design specifications many assumptions were used for simplification. The interaction of these different components was estimated by using engineering judgement and finite element analysis.

At the beginning of the final design phase, we researched various operationally similar tumblers for benchmarking. Some of the leading industries fabricate tumbling systems to separate various substances. These industries have patented designs which have been tested and optimized to suit the process of removing and separating substances. We contacted some of these industries and based on our client needs and constraints, two of the industries that manufacture tumblers that meet are requirement are Didion International and Kramer Industries. We also propose these alternate options in conjunction with our design for the nickel removal from the LDPE strips. An overview of the models from these industries and their specifications is provided.

5.1 DIDION INDUSTRIES

The tumbler model proposed by Didion Industries is RS-100/14 SM Mark 5 Rotary Separator / Metal Reclaimer (Figure 66). The key components for the tumbler system assembly are the similar to our design but this model contains only one drum, a chain drive, trunnion wheels and drum tires. In addition to these components a variable jet burner and a product discharge chute is also included in the design. The variable jet burner is employed at the inlet to increase the rate of the process and to allow smooth travel of the tumbler’s contents.

Figure 66: Didion Industries, RS-100/14 SM Mark 5 Rotary Separator/Metal Reclaimer [35]

Some of the important features and characteristics based on the client needs are [35]:

- Efficient tumbling action for thorough cleaning of LDPE strips from Nickel.
- Throughput of about 3 tonnes per hour of LDPE strips with nickel (1000 strips/ hour).
- The tumbler is 14 feet in length and 5 feet diameter, with an overall height of 7.5 feet.
- The LDPE strips and the nickel is separated automatically.
- The design complies with OSHA regulations for pinch point protection.
- The weight of the assembly is approximately 8.5 tonnes.
- The trunion wheels and thrust rollers are manufactured from wear resistant alloy as well as paint protection for all other components.
- Simple, smooth drive system with very low energy consumption and low maintenance.
- Reduced noise levels and dust escape due to containment in the drum.
- Very low dust collection CFM due to small open area.
- Very simple foundation requirements for minimal installation cost.
- Standard drive components.
- Ease of access to bearings and drive components for maintenance.

Engineering drawing for the tumbler was provided by Didion Industries (Figure 67), which shows the overall dimensions and components of the tumbler. The variable jet burner is not shown in the drawing. The drawing shows discharge of the material and castings from the opposite ends, the material in our case refers to the nickel and the casting as the LDPE strips. The direction of rotation of the tumbler varies based on if the material to be separated is being fed or discharged, the inside lining of the tumbler is designed to accommodate this action. This design feature will allow automatic separation of the strips which will make the design more efficient and less labor intensive. The design also fits within the space constraints. The tumbler will be loading using a forklift which will empty the bin into the tumbler.

[redacted]

Figure 67: RS-100/14 SM Mark 5 Rotary Separator / Metal Reclaimer Drawings [35]

The Didion tumbler model RS-100/14 Mark 5 Rotary Separator/Metal Reclaimer is a good option which can be purchased. The cost of the whole assembly will be CAD $176,500 [35]. This cost will not include installation. Prior to shipping the tumbler it will be tested to ensure proper operation for our specific application.

5.2 1.2 KRAMER INDUSTRIES

On the basis of the design and size of the tumbler required for our application, Kramer Industry's K3060-4 from the K series barrel tumblers was the system proposed (Figure 68). The barrel tumbler design consists of only one tumbler. It is not supported by trunions under the drum but with bearings at either ends which are attached to a robust frame. The chain drive system is located at only one end powered by the variable speed motor.

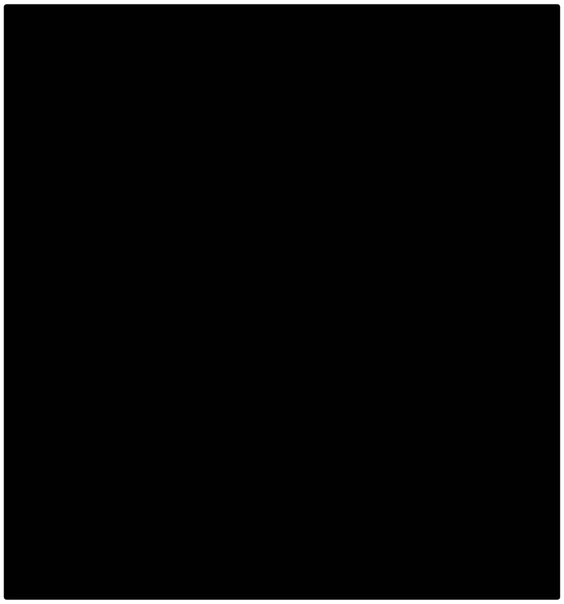


Figure 68: Kramer industries, K3060 Barrel Tumbler [36]

Some of the important features and characteristics based on the client needs are [36]:

- Heavy-duty barrel tumbler system to ensure efficient tumbling action for thorough cleaning of LDPE strips from Nickel.
- The overall dimensions of the tumbler system 42" x 99" x 60" (depth x width x height).
- The capacity of the tumbler is 25.9 ft^3. It will fit about 400 sticks, customization of the tumbler is also optional.
- An electric separating machine is available.

- The tumbler system is provided with a timer to time cycles and overload protection to ensure the motor does not burn out.
- The system comes with swing down guard with safety interlock and sturdy wrap-around housing.
- The inside of the tumbler is lined with a durable coating for heavy duty tumbling.

This tumbler design meets our space constraints and will be able to perform the cleaning and separating of the strips effectively. The loading of the strips will be similar to our design using a forklift but for the unloading the strips and nickel doors are located on the shell. An electric separating machine can be purchased additionally to separate the contents.

This cost of K3060 model will range from about CAD $57000 – 80000 [37].

These two designs have the advantage of being designed by professionals with experience and the design is tried and tested to attain optimum results. This will eliminate the risks associated with interaction of the individual components, which exist in our design as tests were not performed to gauge its performance and further optimize it. Lastly, the two designs are viable options for our application which should be considered to make the final decision.

6 CONCLUSION AND RECOMMENDATIONS

The objectives of this project were to design a system that is safer and less labour-intensive than the current method, improves the current process flow and ensures that there is always a sufficient supply of starter strips. The new design also was required to include a standardized procedure. The proposed Tilted Tumbler System meets these requirements. Its enclosed tumbler system will greatly increase the safety of the workers by containing the dangerous nickel shards safely inside the tumbler. It is less labour intensive than the current process, which requires one employee working eight hours per day, by now only involving an employee for an estimated maximum of three and half hours. As well, with less labour, each day it will clean approximately 60% more strips than the previous 5040. The major components of the final design consist of a tumbler composed of two concentric cylinders, a drive system, support structure, and entry chute. The overall size of the design is 7’2”x9’0”x9’6”, which fits within the allotted space of 15’10”x17’6”x10’9”. The estimated cost of the design was determined to be approximately $92,000 and the operating costs were approximated as $82,000. With these costs, Vale will be able to break even within the second year of the design’s implementation, meeting the need for a three year payback schedule required by the client. The major cost savings can be attributed to the drastic reduction in required employee labour hours, previously costing the company $90/hr effectively.

In addition to our customized tumbler system design, we also provided alternatives for the client in the form of readily available component selections. The client may choose to purchase a tumbler system from either of two manufacturers, Didion Industries or Kramer Industries. These options cover the main functionality range of components included in the customized design. The estimated cost of tumbler assembly from Didion is $176,500 and Kramer Industries provided a range between $50,000 and $70,000. Both of these options also fall within the payback schedule of three years.

The Tilted Tumbler System designed and detailed in this report has been tailored to best meet our client’s needs while adhering to their constraints, therefore we would recommend that they choose to manufacture our design over purchasing ready-made standard assemblies from other manufacturers. However, if the custom design option is chosen, we would recommend more in-depth analytical and numerical analyses be conducted by more qualified individuals before implementation. The analyses conducted by the team are limited in their depth due to the lack of experience and expertise of the design team students. If these qualified analyses cannot be conducted, we recommend as the simplest option, that the client purchase one of the suggested ready-made options from the more qualified and accountable manufacturers.

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