5-2016

Haul Truck Tires Recycling

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Contributions to the Project

For the Haul Truck Tire Recycling project, there were four important aspects the judges would consider. These aspects were: Written Report, Bench-Scale, Poster and Presentation. I contributed doing research, designing the bench-scale drawings, writing some sections and formatting the report, the presentation and the poster. I also made a pamphlet for the bench-scale presentation.

I was involved from the beginning with research of different recycling alternatives such as rubberized asphalt, rubber composite decks, rubber encased railroad ties, rubber mats, and housing.

After evaluating all the ideas the team came up with, we decided to use the tires as Ball Mill Liners in an industrial scale due to the size of Off-the-Road (OTR) tires. Once the idea of using tires as ball mill liners was chosen, I contacted a tire dealership to find out information about their tire production and disposal. This company later provided us with used truck tires, which were used to build the bench scale.

I worked on the ball mill design drawings. First, I used the program SolidWorks to start with the overall bench scale design and to get a better idea of how the bench scale would look like. In order to do the drawings of the bench scale shown in the report, I used the program DesignCad. I had to take the measurements of all the materials used for the bench-scale as well as the constructed equipment. I had to keep up with the changes made to the design during the construction.

For the Report, I worked on the initial formatting part. I organized the sections that would be in the report and then put together all the sections once everyone was done. I redacted the Task parameters, the Environmental and Safety Section and the Regulations Section. I redacted the equations in the Design section as well.

I formatted and set up all the pertinent sections of the PowerPoint Presentation, so that each group member could choose a part to write about. I worked on the Health and Safety section, the Regulations section and the Conclusions section of the presentation as well as the final formatting. The final formatting included proof-reading, adding pictures and fixing the aesthetics of the presentation.

For the Poster, I redacted my sections (the same ones from the report) and also put together and formatted the other team member’s sections. I also made a pamphlet explaining the task parameters, the purpose of the project and our proposed solutions. This pamphlet was handed in to the judges while we were making the bench-scale presentation.

APPENDIX

Haul Truck Tires Recycling

WERC 2016

TASK # 2

Ball Hogs

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Haul Truck Tires Recycling

WERC 2016

TASK # 2

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1.0 EXECUTIVE SUMMARY

The disposal of large Off-the-Road (OTR) tires is an increasingly important concern. These tires can weigh up to 8,450 pounds with an overall diameter and width of approximately 140.7 inches and 45.1 inches respectively. OTR tires are used for mining vehicles such as haul trucks, wheel loaders, backhoes, graders, and trenchers.[1] These new tires cost between $38,000 and $50,000 each, depending on multiple factors including oil prices and the cyclical nature of the industry. Haul trucks contain six tires per vehicle, and mines replace these tires around every 9-12 months.[2] Statistics regarding discarded OTR tires are not provided by the industry as they are for other types of tires. Thus, it is difficult to approximate the number and location of waste OTR tires not only in individual states, but in the U.S. in general.[3] Currently, Minnesota and Arizona are the only states that place regulations and fees on OTR tires. However, Minnesota is the only state that actually tracks them.[3] The Rubber Manufacturers Association (RMA) roughly estimates that OTR tires account for 1% of scrap tires by number and 15% by weight.

When the tires are replaced, the old tires can be discarded with the waste rock in stockpiles at the mining site but more often are landfilled without documentation by an appropriate agency due to lack of federal regulations. Their low density and hollow centers cause them to float to the top of landfills, disrupting the compactness.[4] Also, tires have a heat content 20-40% greater than that of coal which can be very dangerous on the rare occasions that tires catch fire in stockpiles.[5] Furthermore, burning tires release hazardous substances including pyrolytic oil, ash, and smoke, which contain carcinogens, heavy metals, and other toxic compounds.[6]

Due to the large size of OTR tires, there are few facilities that can accommodate their recycling.[3] This leads to increased costs in transporting them to such sites. Transportation costs for a tire taken out of service can be up to $1000. In addition to the freight costs, recycling an OTR tire can cost up to $1500 because of their rugged construction compared to passenger tires which cost around $1 to recycle.[3]

In response to the waste OTR tire problem, the Ball Hogs from the University of Arkansas have designed a solution that recycles OTR tires by using old tires as liners in ball mills for hard rock mines. Ball mills are large cylindrical vessels consisting of an outer shell, an inside liner and a load of metal balls. A motor turns the ball mill using a transmission system causing the metal balls to move in a cascading motion to grind the material fed into the ball mill. Ball mills require liners that are constructed from materials such as steel or rubber. For a 30 ft long ball mill with a

20 ft diameter, a hard rubber liner reinforced with steel can cost $150,000. These liners are replaced at least once a year, creating a substantial upkeep cost for these ball mills.

Metal mines in Bolivia are already using tractor tires to line many ball mills. This technique has been effective for over twenty years. The high import costs of new liners and the low cost of labor has led many Bolivian metal processors to use truck and tractor tires as liners in their ball mills. This construction normally occurs on site using tools like handsaws, drills, torches and knives to cut up tires and manpower to mount these tire-made liners onto mills. However, this is not always the case in the U.S. where labor costs are much higher and the mills are generally larger. Many mines in the U.S. do not have the means to fabricate and install these liners on site; therefore, a third-party solution is proposed that will take a mine's discarded tires and make ball mill liners out of them.

Our solution provides an environmentally and economically feasible process of increasing the life of OTR tires beyond their typical use. This alternative would utilize the engineering and technology that makes these tires strong enough to hold a 400 ton truck. Mining companies would save yearly an average of $70,000 per ball mill liner replacement, and over 780,000 kg of CO_2 per liner. Furthermore, mining companies would earn positive PR, goodwill, and tax breaks. We recommend all mining companies use their OTR tire treads as ball mill liners.

2.0 INTRODUCTION

Recycling OTR tires is not an easy task, as most tire recyclers cannot handle the size of these tires. Currently, many passenger tires are burned for fuel, known as Tire Derived Fuel, or TDF.[7] Tires that are recycled are commonly shredded into Tire Derived Aggregate (TDA) or ground into crumb rubber. TDA is used in a variety of civil engineering applications, including back-fill for retaining walls. Crumb rubber can be used in applications including but not limited to road asphalt, athletic fields, playgrounds, agrimats, molded and extruded products, rubber, plastic blends[8][9] and watering troughs. However, due to growing concerns of toxins being released from tires, many of these applications are now facing greater scrutiny. Moreover, tires in stockpiles and landfills are in danger of leaching into groundwater. Because of an increase in surface area, shredded tires pose an even greater risk of leaching into groundwater than whole tires.[10] This causes great environmental concern, as does pyrolysis which will be addressed under Alternative Uses Considered.

The Ball Hogs' solution to the OTR tire waste problem is a business plan to obtain used tires from mines and then create the mines' ball mill liners out of their old tires. This would encourage the recycling of used OTR tires due to the environmental and economic benefit of the mine. The tire treads can be retrofitted into the ball mill liners using existing mill holes for the current liners. Rubber liners are already used in industry and have proven very effective. The rubber tread in OTR tires is designed to be very resilient and can be suitable for a mill liner after it has been put out of service. Furthermore, the treads of OTR tires resemble the texture of current rubber ball mill liners. Liners made from OTR tires may actually be more durable due to their construction containing 4 ply steel as opposed to the current rubber ball mill liners that only contain 1 ply steel.

Figure 1. Ball Mill in Bolivia

3.0 TASK PARAMETERS

The task consisted of diminishing haul truck tire waste by finding a better disposal solution in order to diminish the nation's growing stockpile of scrap tires.

- Evaluate options to recycle used haul truck tires.
- Review existing and potential markets.
- Consider the total volume of tires generated regionally or nationally.

- Quantify advantages of the proposed option against other current markets.
- Develop a lifecycle cost analysis.
- Address energy minimization, innovative re-use and application in the added value to the solution.

4.0 ALTERNATIVE USES CONSIDERED

4.1 Pyrolysis

Many uses for discarded OTR tires were considered, including pyrolysis. Pyrolysis takes advantage of tires' rich energy density. In its simplest form, pyrolysis consists of decomposing tires in in an oxygen-free environment with high temperatures. An explosion hazard can be created if oxygen infiltrates the system.[11] Pyrolysis mainly produces pyrolytic gas, oils, and char. Ash free oils can then be turned into valuable carbon black, which can be used in a variety of applications, including plastics, electrostatic discharge compounds, high performance coatings, and toners and printing inks.[12] That being said, pyrolysis projects have failed time and again due to operating problems, unsafe and dangerous conditions, a lack of environmental controls, and high cost, among others.[13]

4.2 Tire Derived Fuel

Several businesses use TDF, including cement kilns, boilers at pulp and paper mills, and electric facilities, to name a few. Whole passenger tires can be burned in cement kilns or can be shredded for use as fuel in other facilities. However, OTR tires must be shredded to fit inside the opening to the kiln. In boilers, tires are shredded and mixed with coal or waste paper and wood.[5] Despite the rich energy density associated with tires, some deterrents prevent companies from undergoing TDF production. They include permitting and the requirement of expensive air pollution control equipment, public opposition to burning tires, and boiler operational issues. Even though a TDF additive in a coal-based fuel could result in a less expensive and more efficient fuel than coal alone, the lengthy and expensive permitting process diminishes the economic advantage.[5] Also, hot spots can be created when wires from the tires clog the grates in boilers, thus requiring temporary shutdowns.[5] This results in the tires needing to be de-wired beforehand, which increases processing costs.

4.3 Rubber Mats

Cutting the side-walls off of the tires and creating rubber mats with the treads was considered for a variety of applications. These rubber mats are placed on roads in open pit mines to give better traction to the trucks. They can also be used as flooring, insulation, and roof shingles. However, because of the size of OTR tires, this will not be as feasible.

5.0 BENCH-SCALE OPERATION

5.1 Material List

1. Carriage Bolts
    a. Manufacturer: Hillman Group
    b. Material: Steel
    c. Dimensions: ¼ x 3 -½
    d. Quantity: 58
2. Fender Washers
    a. Manufacturer: Hillman Group
    b. Material: Steel
    c. Dimensions: ¼ x 1
    d. Quantity: 58
3. Hex Nuts
    a. Manufacturer: Hillman Group
    b. Dimensions: ¼-20
    c. Quantity: 58
4. Rubber Washers
    a. Manufacturer: Bridgestone
    b. Material: Sidewall
    c. Dimensions: 2” x 2” x ¼”
4. Drum Barrel
    a. Manufacturer: New Pig
    b. Material: Steel
    c. Dimensions: 23.5’’ OD x 33’’ H
    d. Quantity: 1
5. Radial Tires
    a. Manufacturer: Bridgestone
    b. Material: Rubber with steel mesh incorporated.
    c. Diameter: 30’’

Figure 2. Materials 1, 2, 3 & 4

Figure 3. Drum Barrel

d. Dimensions: 275/55/R18

e. Quantity: 4

6. Balls

a. Manufacturer: Fox Industries of New Jersey

b. Material; Steel

c. Diameter: 1 in.

d. Quantity: 600 lbs.

7. Bands

a. Material: Steel

b. Width: 6.25’’, 8.75’’, 9.5’’

c. Quantity: 3

8. Horse Stall Mat

a. Manufacturer: Tractor Supply Co.

b. Material: Recycled rubber

c. Dimensions: 4’ x 6’ x ¾’’

d. Quantity: 1

9. Steel Plates

a. Supplier: Ozark Steel Co.

b. Material: Steel

c. Dimensions: ⅜’’ x 20’’

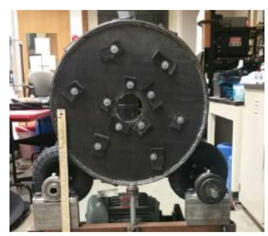

Figure 4. End View of Mill

5.2 Design

The driving parameter used to design the bench scale model was the power requirement of the ball mill. A 55 gallon drum was used as a shell for the mill, and power calculations were made using equations 2 and 3. The approximate power required to run the bench scale mill was calculated at steady state to be approximately 2hp. The startup required much more power and torque. So, a 5 hp motor was selected based on availability and costs. The critical speed of the mill based on the dimensions was calculated using equation 1. An appropriate gear reduction system was designed to run the mill at 47 rpm, which is 77% of the critical speed. This speed ensures adequate cascading of the balls. After sizing all the major design parameters, a frame was designed to house the apparatus with a minimalist approach, which resulted in making the apparatus compact, sturdy and safe.

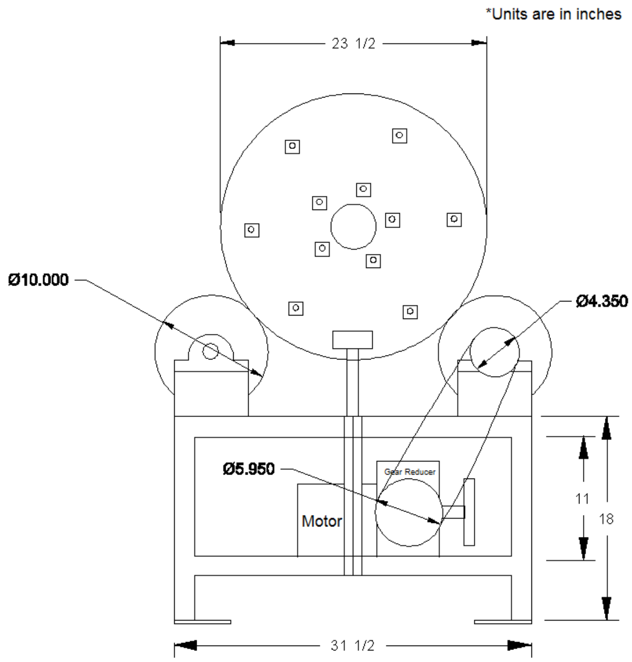

Figure 5. Front View of Ball Mill

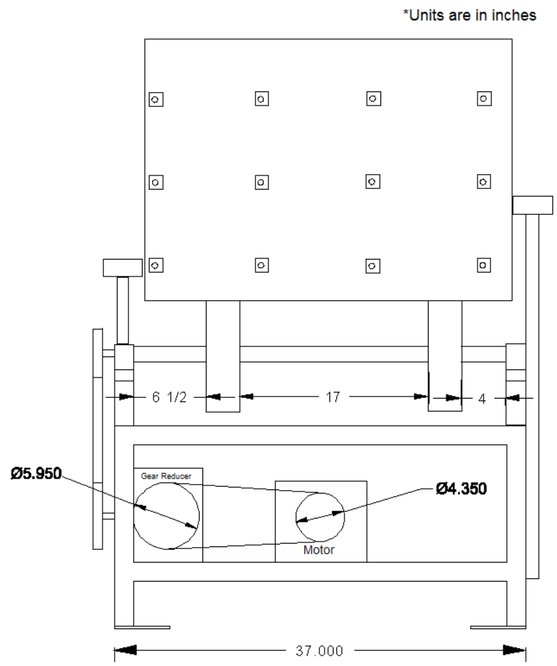

Figure 6. Side View of Ball Mill

Equations:[14]

$$C_s = \frac{42.3}{\sqrt{D}} \qquad (1)$$

Where:

C_s = Critical Speed, rpm

D =Inside Diameter of the mill, m

$$S_s = \frac{1.102\ (B - 12.5\ D)}{50.8} \qquad (2)$$

Where:

Ss = Ball size factor, kW/ton

B = Diameter of the ball, m

D =Inside Diameter of the mill, m

$$kW = M_c\left[\left(4.879 * D^{0.3}\left(3.2 - 3\ V_p\right)f\left(1 - \frac{0.1}{2^{9-10\ f}}\right)\right) + S_s\right] \qquad (3)$$

Where:

M_c= Mass of balls, ton

D= Inside diameter of the ball mill, m

V_p= Volume of the load occupied by balls, %

f= Fraction of critical speed

S_s= Ball size factor, kW/ton

5.3 Construction

Before any tread installation took place, the barrel was reinforced on the outside with two steel bands 1/8" thick. Holes with 4'' diameters were made on both ends of the barrel for the feed entrance and exit.

The construction of the ball mill drum began by measuring the height of the barrel, which was then used to determine the length of the tire treads. The sidewall from each tire was manually removed, leaving only the tread. The tire treads were cut shorter than the length of the barrel using a bandsaw ensuring enough space for a rubber liner to protect the endplates inside each end of the barrel.

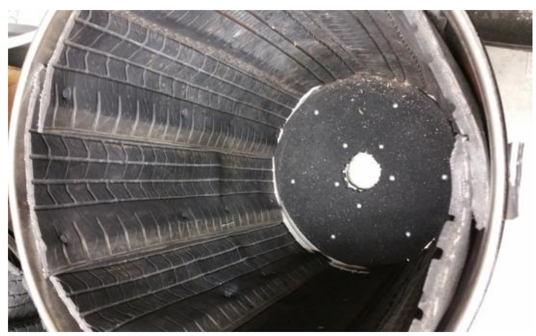

Figure 7. Treads Inside Ball Mill

Subsequently, the treads were cut and overlapped inside the barrel longitudinally and bolted to the barrel using carriage bolts as shown in Figure 7. The holes for the bolts were made using a 3/8'' drill bit, and the treads were overlapped to lift the steel balls in the drum when it rotates. The first hole was drilled through the tires and barrel from the inside. Then, the carriage bolt was inserted from the inside the barrel. The 2^{nd}, 3^{rd} and 4^{th} bolt holes were drilled from the outside. The area around each tire perforation was counterbored to allow the bolt to fit snugly inside the tires minimizing the chance of steel balls shearing off the bolt head.

The sidewall was then cut into small square pieces, and holes were drilled through each piece to make rubber washers. After the bolt was inserted, a small piece of the cut sidewall was placed around the bolt-end on the outside the barrel followed by a fender washer and a hex nut to tightly secure the carriage bolt, as shown in Figure 2. Because the bolts were protruding outside the barrel, they were grinded off. After each tire was installed, a grinding stone head was used against the exposed bead to grind away the exposed sharp metal.

Once all the treads inside the barrel were installed, the rubber layers were fastened on the inside of the end plates using rubber horse stall mats. They were cut in a circular manner, using the inner diameter of the tread-lined barrel along with the holes in both end plates to ensure a correct fit, as shown in Figure 7. The bolting procedure for these mats was the same as for the treads, the only difference being a smaller drill bit was used to maintain the integrity of the mats. As before, the bolt excess was ground off to keep them from protruding from the ends of the barrel.

Figure 8. Finished Apparatus

5.4 Safety Considerations

The following safety considerations are needed to be kept in mind while operating the bench scale model:

- Electrical Shock: The motor on the bench scale model runs on single phase 220V power supply.
- Physical Hazards: The bench scale when charged with balls weighs close to 1300 pounds which can be injurious if any component fails and the structure collapses. The barrel has bolts with sharp edges. The tires on the drive end and the idler can blowout and cause serious injuries to anyone in the vicinity.
- Mechanical Hazards: The bench scale model has two belts on it, both of which are moving parts hazards. Also, the barrel will be rotating at approximately 45 rpm which is also a moving hazard.
- Thermal Hazard: The 5 hp motor on the model can heat up during operation potentially causing it to be a thermal hazard.
- The required personal protection equipment (PPE) for safe operation of this apparatus is safety glasses, steel toed shoes, long pants and work gloves.

- Guards were placed around the mill to prevent touching by anyone operation or observing the mill operation.

5.5 Operational Procedure

<u>5.5.1 Safe Start-up Procedure:</u>

1. Ensure that the operator is equipped with all the required PPE
2. Charge the ball mill with steel balls up to 40% of the mill volume
3. Ensure all the moving parts are well lubricated and aligned
4. Plug the motor into the power supply
5. Turn the switch for the power on
6. Charge the mill with the feed and start milling

<u>5.5.2 Safe Shutdown Procedure:</u>

1. Turn the switch for the power off
2. Let the mill come to a complete stop

<u>5.5.3 Emergency Shutdown Procedure:</u>

1. There is an emergency switch located on the frame
2. In case of an emergency, flip the emergency shutdown switch and stay clear of the moving parts

5.6 Experimental Results

The Ball Hogs' mill ran without a feed simulating the worst possible operating conditions. This scenario created the greatest amount of wear on the liner because by running a mill on empty, the greatest amount of stress is put on the liner since there is no feed material to cushion the impact of the balls hitting the liner. The tire liner held successfully during the bench scale operation and did not show any wear. The bench scale model showed minimal vibration and ran in a balanced manner. The balls in the bench scale moved in a cascade motion, and the overlapping design of the tire liners mimicked the lifting motion provided by the liners currently used in the industry.

6.0 FULL-SCALE DESIGN

To successfully convert a bench scale tire installation inside a ball mill to full scale, several considerations are necessary. First, the size of a full scale ball mill is more than ten times the size of the bench scale mill. Our bench scale mill is 23.5in. by 33 in. compared to a full scale mill that is roughly 20 ft. by 30 ft.

The size of the tires for a bench scale mill varies greatly from the size of the tires for a full scale mill. For the bench scale mill, automotive truck tires were transported to the site and dismantled by hand onsite. The sidewalls were removed using a box cutter and the tires were cut to the necessary lengths using a bandsaw. The protruding metal wire from the steel mesh was then ground away using a grinding stone, and the tires were manually transferred into the mill and bolted down ensuring adequate tire overlap.

For the full scale mill, very large and heavy mining truck tires will be used. Heavy machinery is required to move the tires to and from any location. Unlike passenger tires, tires of this magnitude would be dismantled by a third party. The third party would transport the tires, remove the side walls, cut the treads to the specified length dependent upon the size of the mill, drill the bolt holes based on the mill blueprints, and return the tires to the mine for installation.

For the bench scale mill, the bolt holes were drilled from the outside of the mill through the steel wall, then through the overlapped tires on the inside of the mill. Once visible from the inside of the mill, the perforations were counterbored allowing the bolt to sit inside of the tire. This minimizes the chance of steel balls shearing off the bolt head. Then the rubber washer, metal washer, and hex nut were fastened onto the bolt on the outside of the mill. In contrast, for a full scale mill, installers must remove the old liner and install the new one aligning the bolt holes on the tires to the bolt holes on the mill.

Considering the bolt holes are designed in rows longitudinally down the length of the mill and a mill of this size is large enough for workers to stand inside, multiple people can work on different bolt holes along the same row at the same time. For example, workers would bolt the liner simultaneously at 5ft. inside, 10ft. inside and so on. All bolting would occur along one row of bolt holes at a time. Once the bolts are fasted along the entire row, the mill can be rotated to fasten the next row of bolt holes until the installation of the liner is completed.

7.0 BUSINESS PLAN

At Newmont's Cripple Creek and Victor Mine (CC&V) operation, 122 tires were taken out of service last year. Of these 122 tires, 71 were replaced because they were worn down, and the remaining 51 were replaced because they were damaged. Currently, CC&V does not have a permit to bury these tires, nor do they want to; therefore, they have an agreement with Western Tire Recyclers of Utah to properly dispose of them. Western Tire charges CC&V up to $700 for every tire they pick up. This cost is necessary to cover the liabilities associated with OTR tires.

Western Tire has developed a machine that is unique in its ability to cut, grind, and dismantle these tires. This is a newly patented process that took over ten years to develop.

The objective of this business venture is to recycle used OTR tires and transform them into ball mill liners. There are three fundamental pillars to this business plan. First, the tires must be collected at a mining site where they are being disposed. Preferably, the tires to be collected should be those that are not completely worn down. Preference will be given to those that are punctured on the side wall and have at least three to four inches of rubber left over the steel mesh. A competitive fee of approximately $700 per tire will be charged to the mining company.

Second, these tires will be hauled by a trucking company which will charge for their transportation to a facility that can handle them. The Ball Hogs have spoken with Western Tire, and they have shown great interest in the project. They have the machinery, expertise and personnel needed to handle these tires. Western Tire will need technical specifications of the ball mill that these tires will be lining along with the design of the liner that will be created in order to cut the tires to the required size, wasting the minimum amount possible. The tire recycler will cut the treads, drill holes to match the bolt pattern of the customer's ball mill, and pre-fabricate sections of the liners at their facility. The ball mill liners will then be fabricated to fit purchase orders from mining companies.

Third, the sections of prefabricated liners will be shipped to the mining facilities to be installed on their respective ball mills. Mining companies cannot afford to have a ball mill down for re-lining for more than a day; therefore, the liners must be installed as quickly as possible. Since the pre-fabricated sections will already have the matching bolt pattern, installers should be able to fasten them quickly. Most mining plants have personnel available to deal with procedures like this. If need be, the installation work could be sub-contracted.

The economic aspect of the operation can be exemplified using the mill CC&V owns, which is 20 feet in diameter by 30 feet in length. They have reported the cost of the liner for this mill to be $122,000 without hardware or installation. This liner is sold to CC&V by F.L. Schmidt, the manufacturer of their ball mill. The price charged to customers must be significantly lower than that of a new liner in order to be an appealing choice, given that liners made out of recycled tires are a fairly new invention and may give the customer a sense of skepticism.

The price of these liners must cover the cost of transportation from the mining site to the tire recycler and back to the plant where the liners will be installed. The cost of cutting, perforating and assembly of the liners must also be covered, along with the cost of hardware and installation. Profit will be made after these fixed costs have been covered. Mining companies that provided OTR tires will be given a price reduction to match what was charged to them to recycle the tires. Therefore, if $700 per tire was charged, a reduction of the price per tire that went into the making of the mill liner will be given. Since parts of the old tire will still remain after making the liner, part of the $700 will need to be retained for proper handling of the remaining parts of the tire. This price will be adjusted in the disposal cost of the liner.

Returning to the CC&V ball mill example, the liner for their 20 feet by 30 feet mill would have a circumference of about 63 feet and would need approximately 28 tire treads to be covered completely, given that the cut treads will be approximately thirty six inches wide and installed longitudinally to account for the necessary overlap to lift the balls. The treads unfold to a length of 36.65 feet. Ideally, 10 foot long pieces will be cut because they are easier to handle. The thirty feet in length would require three 10 foot pieces in length. In the case of smaller mills, the treads would have to also be cut longitudinally because their width is too large to adequately conform to the curvature of the mill’s shell.

8.0 ECONOMIC ANALYSIS

8.1 Liner Cost

In order to be able to grasp the economic benefits of using liners made out of recycled OTR tires, the economics of this project must be compared with the current procedure of mounting new rubber liners on the mill. In terms of liner cost only, new rubber liners cost $122,000 for a mill that is 20 feet in diameter by 30 feet in length. The inner surface area of this mill is 2,513 square feet which gives a liner cost of $48.54 per square foot. This price does not include the cost of transportation to the mining site, hardware, or installation. The hardware and installation cost will be equal for the liner made out of recycled treads or for the new liner. The cost of transportation from the tire recycler to the mining plant will be $80 per ton, whereas it would cost $8,000 for the new liner to be transported from the importer to the mining plant.

8.2 Installed Liner Cost

The economic comparison between both installed liners would be $48.54 per square foot of a new liner versus $19.89 per square foot of the recycled OTR tire liner. This cost includes the tire liner fabrication at the recycler and the business profit for whoever sells these liners. The price of a liner made out of OTR tires is approximately two and a half times less expensive.

Using the CC&V mill as an example, the cost of a new liner includes $122,000 for the actual liner, plus $20,000 in materials cost, plus a labor cost of $30,720, plus $8,000 in shipping, minus $30 per ton that mining companies are paid for their used liners. This gives a total cost of $179,882 which comes to $71.57 per square foot of installed liner.

The cost of a liner made out of recycled tires includes $45,000 for fabrication, plus $5000 of business profit, plus $20,000 in materials cost, plus a labor cost of $30,720, plus a transportation cost of $80 per ton, plus a disposal cost of $130 per ton which includes transportation and recycling. This gives a total cost of $108,818 which comes to $43.30 per square foot, over a 40% cost reduction.

8.3 Liner Disposal

Once the liners made out of these huge tires are consumed, the recycler has agreed to dispose of them to recover steel from the bands and shred the remaining rubber for alternative uses. As stated above, this would have a cost of $130 per ton which includes transportation and disposal costs. This cost is different than what the mining company would earn at the time of disposing traditional rubber liners. Liner suppliers like F. L. Schmidt pay the mining companies $30 per ton of used traditional liner. Because new liners would no longer have to be created or disposed of, and huge tires would be recycled to make the liners, this business plan would create a very large environmental benefit.

8.4 Total Cost Analysis

The comparison between the cost of current liners and the tire liners was done using two different methods:

1. To get an idea of the yearly cost difference, average yearly savings were calculated. The sensitivity parameter used for this comparison was the lifespan of the tire liner (refer to Figures 9 and 10). This analysis showed that if the lifespan of the tire liners was more than 5 months there would be a significant saving. The expected lifespan of these liners are estimated to be 10-12 months which would result in $49,300 - $71,063 average savings per year (refer to Table 1).
2. The cost analysis of the tire liners over the lifetime of the ball mill (assume to be 50 years) was done by comparing the net present worth of the current liners to the tire liners. Again, the sensitivity parameter used for this comparison was the lifespan of the tire liners. The

savings over 50 years for 10-12 month life of tire liners were $399,294 - $544,320 (refer to Table 1).

Furthermore, both a best and worst case scenario were modeled. The worst case scenario would be replacing the liners every six months. This scenario would result in a loss of $180,000 over 50 years. The best case scenario would be replacing these liners every 16 months. This scenario would bring with it $725,554 in savings over 50 years. The economic analysis showed that using tire liners would result in significant reduction in the operating costs of ball mills (refer to Figures 9 and 10).

Table 1. Analysis of Tire Liner Life

Tire Liner Life (Months)	Savings (Tire Liners - Current Liners)	Average Yearly Savings	Average Yearly Reduction in Carbon Footprint (kg)
6	($180,777.08)	($37,754.41)	1,302,925.99
7	$26,364.08	($7,285.28)	1,120,516.35
8	$181,764.07	$16,654.75	977,194.49
9	$302,582.85	$34,065.68	872,960.41
10	$399,294.81	$49,300.25	781,755.59
11	$478,353.60	$60,182.08	716,609.29
12	$544,320.58	$71,063.91	651,462.99
13	$600,012.29	$77,593.01	612,375.21
14	$647,898.55	$86,298.48	560,258.17
15	$689,354.65	$92,827.58	521,170.39
16	$725,554.27	$97,180.31	495,111.87

Table 2. Economic Model for CC&V Gold mine owned by Newmont

Economical Model for CC&V Goldmine owned by Newmont					
Ball Mill			**Liner Weight**		
Diameter Of the Ball Mill, D	20	ft	Surface area of cut tire piece per unit	90	ft^2
Length of the Ball Mill, L	30	ft	Number of tires required	28	
Surface Area of the Ball Mill, A	2513.27	ft^2	Appoximate weight of cut tire piece	4000	lbs
			Weight of the new liner	55.85	tons
			Weight of the used liner	27.93	tons
Case I			**Case II**		
Current Liners			**Tire Truck Liners**		
Liner Cost per unit change	$ 122,000.00		Tire liner Fabrication Cost	$45,000	
Liner Cost per sq ft	$ 48.54	$/ft^2	Profit	$5,000	
			Liner Cost per sq ft	$19.89	$/ft^2
Installation & Material Costs			**Installation & Material Costs**		
Labor Cost per Hour	$ 160.00	$/hr	Labor Cost per Hour	$ 160.00	$/hr
Installation time	24	hr	Installation time	24	hr
No. of Contractor's	8		No. of Contractor's	8	
Labor Cost	$ 30,720.00		Labor Cost	$ 30,720.00	
Material Cost	$ 20,000.00		Material Cost	$ 20,000.00	
Transportation Costs			**Transportation Costs**		
Shipping Costs for the liners	$ 8,000.00		Liners from the Recycler to the mill	$ 80.00	$/ton
Disposal Costs			**Disposal Costs**		
Liner Disposal Costs	$ (30.00)	$/ton	Liner Disposal Costs	$ 50.00	$/ton
			Transportation	$ 80.00	$/ton
Total Cost of Replacement	$ 179,882.24		Total Cost of Replacement	$ 108,818.33	
Cost of Replacement per sq. ft	$ 71.57	$/ft^2	Cost of Replacement per sq. ft	$ 43.30	$/ft^2
Net Present Worth Analysis of liners for the Life of the Ball Mill					
Life of the Ball Mill,N	50	years			
Interest Rate	15%				
Case I			**Case II**		
Current Liner life	12	months	Tire Liner life	10	months
Total Replacements	50		Total Replacements	60	
Interest per period	0.15		Interest per period	13%	
Total NPW	**($1,377,824.56)**		**Total NPW**	**($978,529.74)**	
NPW per surface area of Ball Mill	**($548.22)**		**NPW per surface area of Ball Mill**	**($389.34)**	

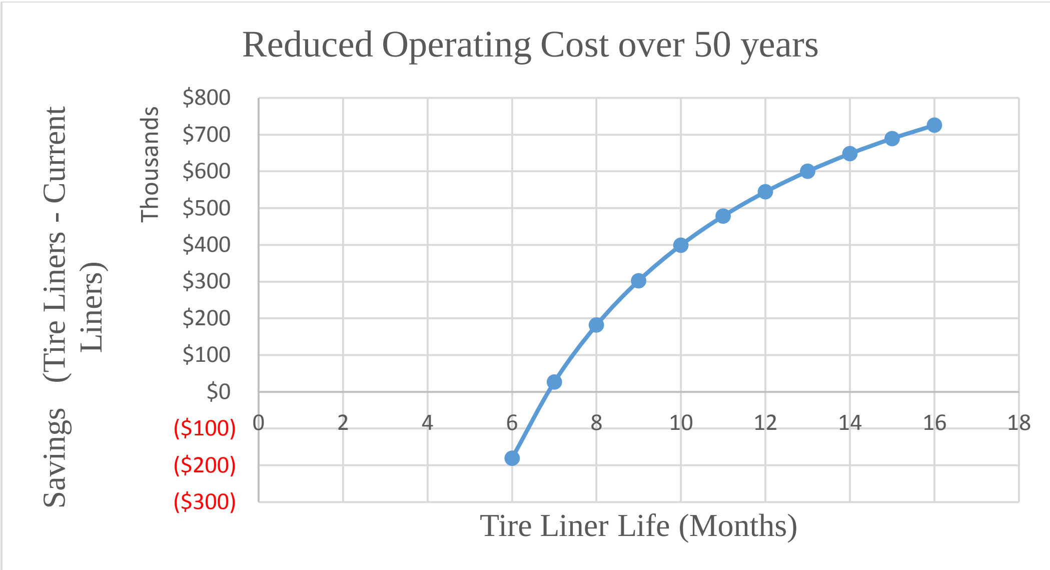

Figure 9. Reduced Operating

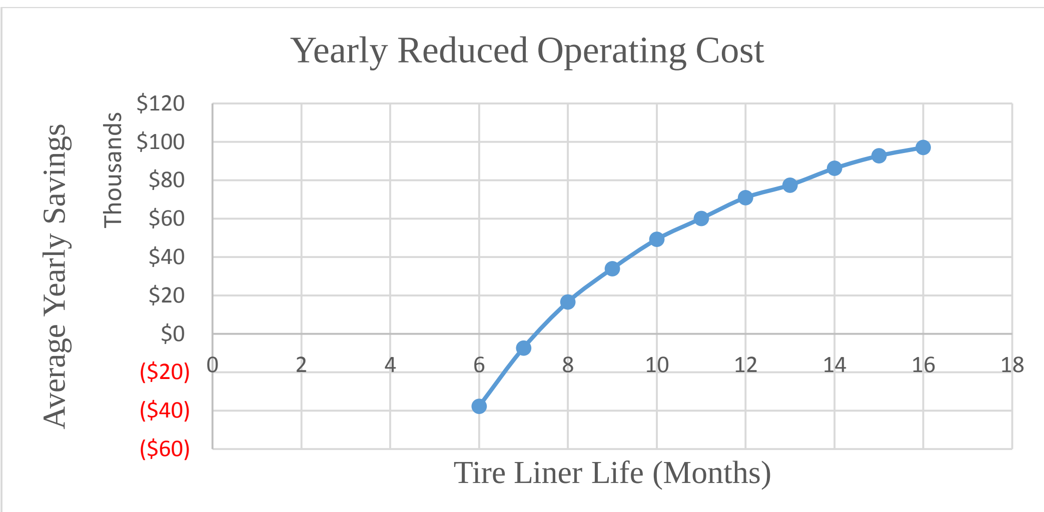

Figure 10. Yearly Reduced Operating Cost

9.0 Life Cycle Analysis

The life cycle analysis for this project must include an analysis of the environmental impact of using OTR tires as ball mill liners. Since the recycling of used OTR tires involves them being re-used as ball mill liners, there will be a decrease in the production of new traditional liners. This decrease will minimize energy usage and rubber usage for the production of new liners which comes out to be reduction of approximately 7800 kg of CO_2/ton of product. [15] Also, this gives the OTR tires a second life, thus reducing 3850 kg of CO_2/ton of product. [16]

The total reduction of CO_2 per liner change for the ball mill at CC&V comes out to be 651,463 kg. This project has a tremendous environmental impact with average reduction of 781,755 - 651,462 kg of CO_2 per year for the liner life of 10 - 12 months.

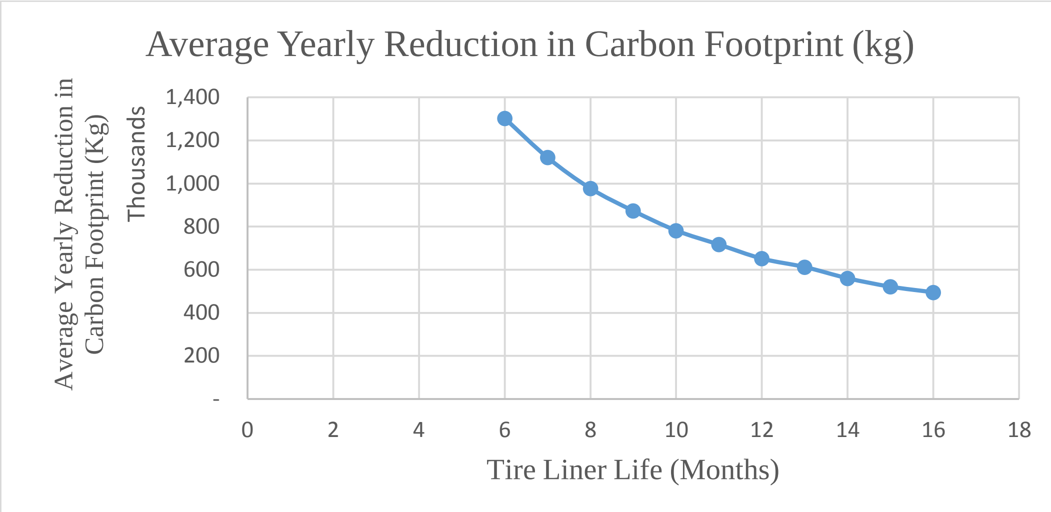

Figure 11. Average Yearly Reduction in Carbon Footprint (kg)

10.0 ENVIRONMENTAL AND SAFETY

10.1 Waste Generation Considerations

The tires will be significantly reduced in volume and mass after being used as liners for the ball mill. This decrease in volume will make the tires thinner, which will facilitate their grinding for future recycling. This will be a good solution to OTR tires considering most shredders cannot accommodate them.

Once the rubber in the tires is reduced to crumbs, they can be used as additives for asphalt or other applications. The steel collected from the tires will be recycled in steel mills and manufactured into new steel.

10.2 Environmental Considerations

Tires accumulated in stockpiles have been considered an environmental problem because when exposed to water and sunlight, they create a perfect environment for hatched larvae.[17] The increasing amount of stockpiles escalates this problem, which can be avoided by storing the tires to be recycled in dry and closed environments. Once the tires are shredded, hatching larvae will no longer be a problem.

10.3 Chemical Considerations

There are no chemical considerations regarding the use of scrap tires as liners since the production method only involves mechanical machinery.

10.4 Worker Safety and Health

Workers should be trained in how to prevent and put out tire fires. Even though this would be a rare occurrence, workers would have proper training following OSHA's (Occupational Safety and Health Administration) law and regulations for worker safety.

Machinery operators should have training on how to manually operate the machinery used to cut the tires, as well as how to install the produced liners properly. All workers should have proper personal protection equipment such as hard hats, eye protection, safety gloves (especially against sharps and cuts) and protective clothing.

11.0 REGULATIONS

Even though OTR tire recycling is highly encouraged by the U.S. Environmental Protection Agency, there are no federal regulations for used OTR tires, since they are not considered hazardous materials. [18] OTR tires generated by the mining industry are generally disposed of on site because of high transportation and processing costs.

Although OTR tires are not federally considered a hazardous material, they are still considered solid waste for the purpose of this project. Since the business plan is based on a company located in Colorado, their state regulations on solid waste would be considered. Based on Colorado's statutes, the following articles for solid waste would be considered: Title 30 Article 20 Part 1 (for the Solid Waste Facilities), Title 30 Article 20 Part 10 (Solid Waste Disposal Limitations), and Title 30 Article 20 Part 14 (Waste Tires). The Regulations Pertaining to Solid Waste Sites and Facilities: 6 CCR 1007-2 Part 1 would also be considered for Colorado.[19]

11.1 Permitting

In order to be in compliance with legal regulations regarding the transportation, storage, and hazards involved in solid waste disposal, the following permitting issues should be considered.

11.1.1 Solid Waste Recycling and Storage Permitting Issues

Scrap tires are considered solid waste. Therefore, OTR tires will be considered solid waste when taking permitting issues and regulations into consideration. The waste storage and recycling will be done following the Code of Federal Regulations, Title 40, Chapter I, Subchapter I, Part 243, Subpart B, Sec. 243.200-1. This section refers to how solid waste should be stored, so that it does not constitute a fire, health, or safety hazard. The scrap tire collection facility should be registered and licensed by the state's EPA.[20]

The tire transporters should have a legal permit that allows them to transport the OTR tires. The registration requirements and price vary depending on the state, but the transporters should comply with the regulations regarding transportation, tracking, storage and management.

11.1.2 Air Quality Permitting Issues

When tires are in stockpiles, they could be subject to arson. The air pollution caused by these fires is harmful to the environment and also to the general public that could breathe these pollutants. When the tires are stored, they should be kept in a safe location to avoid vandalism.

11.1.3 Public Health Permitting Issues

If all the regulations mentioned in the previous sections are followed, the tires' storage, transportation, recycling and delivery will not cause any public health issues.

12.0 CONCLUSIONS AND RECOMMENDATIONS

1. Currently, most OTR truck tires are buried, this approach is extremely harmful to the environment. Many other approaches are being taken to recycle these tires; however, many tires are not being recycled creating room for new ideas.
2. Using OTR tires as ball mill liners requires the generation and disposal of less rubber and provides a solution for the use of OTR tires beyond their normal useful life span.
3. Using OTR tires as ball mill liners also is an economically viable solution saving companies with ball mills 40% of their costs to replace the ball mill liner each year.
4. The making of OTR tires requires such extensive engineering that it would be wasteful to not take advantage of all the research, technology, and effort that went into making them as durable as they are. They should be recycled in an alternative way that utilizes their strength and durability, such as ball mill lining.

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