



Chip Recycling: Recycling of Chips from BZZ Conditioning Processes

A Major Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

Submitted by:

Sean Dyer
Bao Ngo
Kurt Wivagg

Submitted to:

Project Advisor:

Prof. Yiming (Kevin) Rong

Project Liaison:

Dr. Han Zhang, Saint-Gobain Abrasives.

April 25th, 2007

Abstract

This project, done in conjunction with Saint-Gobain Abrasives, responds to the rising cost of nickel and chromium, the major components of stainless steel by conducting a comprehensive cost analysis of the stainless steel production and recycling processes. Background research was performed with company surveys for important information about specific machines, which recycle stainless steel chips. With these data, conclusions were prepared about the cost-effectiveness of recycling as opposed to selling or dumping the stainless steel chips. A cost structure analysis and new recycling methods for specific applications were proposed.

Acknowledgments

We would first and foremost like to thank Sha Li and HongTao Sun. Sha and HongTao are currently studying Mechanical Engineering at the Huazhong University of Science and Technology. Through a research project system similar to WPI's IGSD, they were able to study at WPI while assisting us in research for this project. They also did extensive work in analyzing current chip separation methods and we are grateful for their help and efforts. We would especially like to thank Sha his work done on this project which can be found in Sections 4.1 and 6. We would like to thank Dr. Han Zhang from Saint Gobain Abrasives for proposing this project and for providing us with guidance and information when we needed it. We would like to thank Professor Yiming Rong for all his help and guidance throughout this project, and for being our advisor. We would also like to thank Professors Sisson and Koleci for the help that they have given us along the way. Also thanks to Mike Vande Leest with the Dings Company for the information he has given us about certain machines. Finally, we would like to thank Adam Foley for the help that he has given us.

Table of Contents

Abstract.....	ii
Acknowledgments.....	iii
Table of Contents.....	iv
List of Figures.....	vi
List of Tables.....	vii
1: Introduction.....	1
2: Background.....	3
2.1: Stainless Steel Usage.....	3
2.2: Nickel and Chromium Resources.....	3
2.3: Chip Producing Processes - Grinding.....	7
2.4: Chip Recycling Processes.....	9
2.4.1: Settling Tank.....	9
2.4.2: Magnetic Separation.....	10
2.4.2.1: Overband Magnets.....	10
2.4.2.2: Drum Magnets.....	11
2.4.2.3: Eddy Current Separators.....	12
2.4.2.4: Suspension Magnets.....	13
2.4.2.5: Pulley Magnets.....	14
2.4.3: Cyclonic Separation.....	15
2.4.4: Dissolved Air Separation.....	17
2.4.5: Briquetting.....	17
2.5 Scrap Economics.....	18
2.5.1: Steel Scrap End Markets.....	19
2.5.1.1: Basic Oxygen Furnace.....	20
2.5.1.2: Electric Arc Furnace.....	21
2.5.2: Types of Scrap.....	22
2.5.3: Scrap and Iron Ore Price Variation Comparison.....	23
2.5.4: Scrap Quality and its Effects.....	24
2.6: Environmental Aspects of Recycling Grinding Chips.....	26
3: Methodology.....	30
3.1: In-depth literature research.....	30
3.2: Data Analysis.....	30
3.2.1: BZZ Process Analysis.....	31
3.2.2: Chip Properties Analysis.....	31
3.2.3: Stainless Steel Market Analysis.....	31
3.3: Survey Industry Sectors Applicable to Project.....	32
3.3.1: Grinding Industry.....	32
3.3.2: Manufacturers of recycling machines.....	32
3.3.3: Metal recycling industry.....	32
3.3.4: Steel Mills.....	33
3.3.5: Dumps and Waste Sites.....	33
3.4: Synthesis.....	33
3.5: Cost Model.....	34
3.6: New Model.....	35

4: Results.....	35
4.1: Feasibility of Methods	35
4.1.1: Vibration Separation	36
4.1.2: Separation by Melting.....	40
4.1.3: Eddy Current System.....	41
4.1.4: Magnetic Separation	46
4.1.5 Preliminary Study on New Methods	47
4.2: Cost Structure	54
5: Conclusions and Recommendations	58
6: Ideas for Future Consideration.....	59
6.1 Flotation Separation	59
6.2 Gravimetric Separation	60
6.3 Flow Separation	60
6.4 Flocculation Separation.....	61
References.....	62
Appendix A – Machine List.....	64

List of Figures

Figure 1 One-Year Nickel Prices.....	6
Figure 2 Five-Year Nickel Prices.....	6
Figure 3 BZZ Grinding Wheel.....	8
Figure 4 Grinding Process	9
Figure 5 Drum Magnet.....	11
Figure 6 Eddy Current Separator	13
Figure 7 Suspension Magnet System.....	14
Figure 8 Pulley Magnet System.....	15
Figure 9 Cyclonic Separator	16
Figure 10 Dissolved Air Separation Unit.....	17
Figure 11 Briquetter.....	18
Figure 12 Diagram of Basic Oxygen Furnace	20
Figure 13 Diagram of Electric Arc Furnace.....	22
Figure 14 Recycling Process.....	34
Figure 15 Ferrotitanium process 1	38
Figure 16 Ferrotitanium process 2	39
Figure 17 Eddy Current diagram	42
Figure 18 Eddy Current Magnetic Field Diagram	44
Figure 19 Magnetic Separation Diagram.....	46
Figure 20 Properties of 304 Steel.....	48
Figure 21 304 Stainless Steel Chips.....	49
Figure 22 Magnet used in experiment.....	49
Figure 23 304 Chips with Magnet.....	50
Figure 24 304 Chips after Magnetization	50
Figure 25 CAD Drawing of Toroid	51
Figure 26 3D CAD Model	52
Figure 27 Another view of the 3D Model.....	53
Figure 28 Revenue vs. Tons and Time graphs.....	57

List of Tables

Table 1 World Mine Production, Reserves and Reserve Base by Region (USGS, 2007).....	4
Table 2 World Mine Production, Reserves, and Reserve Base by Country (USGS, 2007)	5
Table 3 Average Annual Price of Ferronickel (Stainlesssteel, 2007).....	6
Table 4 Impurity Percentages in Various Steelmaking Raw Materials as of 1992	25
Table 5 Comparison of Scrap and Primary Metal Components	26
Table 6 Main Environmental Impacts of Steelmaking Units or Operation	29
Table 7 Separation Methods Outline	36
Table 8 BZZ Chip Size and Densities.....	40
Table 9 Steel Making Process Cost Structure.....	54
Table 10 Alternative.....	55
Table 11 Recycling Process	55

1: Introduction

For over a hundred and fifty years, steel making has been of great importance to the building of industrial America. Before the 1850s, steel was not widely used, and for the most part, was entirely unheard of in some areas of the world. However, beginning in the 1850s with Henry Bessemer's Bessemer process, steel was quickly being produced cheaply and in large quantities. This process gave steel the advantage over wrought iron. As with most metal processing, steel acquires surface defects during its production. A common way of removing these surface defects is by a process called abrasive chip removal. The process utilizes a highly abrasive grinding wheel, which grinds off a small portion of the surface in order to remove surface defects and impurities. This process produces small grain-size steel chips, and Saint Gobain Abrasives is looking for a way to recycle these chips.

With the prices of nickel and chromium currently on the rise, it is becoming increasingly more expensive to produce steel. With the price rising, recycling the steel chips from the abrasive removal process is beginning to look more appealing to companies. As these chips are very small, 200kg to 500kg worth of chips will take up a great volume because they are not uniformly shaped. Companies will be looking for economical and ecological ways to recycle their chips in order to free up the space taken by the chips. These companies may also be looking to recycling to increase ecological friendliness, or perhaps they are looking to recycling as a way to reclaim the steel chips in order to produce more steel overall.

This project will identify and compare current recycling methods available to the industry and describe in detail the benefits associated with each method. Current

collection methods for steel chips will also be identified and described in detail. Additionally, metallurgical mixing table for various grades of steel will be created in order to identify which types of steel can be melted down to create new steel from recycled chips. Lastly, a possible design for a recycling station or plant will be created in order to provide companies with an on-site or regional recycling option.

Current abrasive removal processes create anywhere from 200kg to 500kg of chips an hour. Recycling these chips is imperative to reclaiming lost steel from the process and to providing an economical alternative to throwing out the chips. Currently, there are several recycling methods for these chips including briquetting and melting. Saint Gobain offers their customers the abrasive wheels to remove material with, and they are looking to be able to offer suggestions on what their customers can do with the steel chips once they have been removed from the material.

This project is intended to develop for Saint Gobain Abrasives, a market study which illustrates the necessity of chip recycling, a technical survey of chip recycling, and also a design for a chip recycling station and plant. The technical survey will include an explanation of current processes and the principles behind them, while listing the possible constraints for each particular system. The design for a recycling station or plant will take into account the different conditions and will place emphasis on the guidelines for designing such a facility.

2: Background

This section will detail the background information that is most important to the context of our project. To create a comprehensive cost analysis of chip recycling, it is first necessary to have a good understanding of the processes involved. These processes include stainless steel usage, chip producing processes, chip composition, and chip recycling processes. It is also necessary to review current recycling processes in order to analyze their technical principles and create a cost structure analysis.

2.1: Stainless Steel Usage

Stainless steel is used around the world in many different environments from in the home to in industry. It is important to note that stainless steel is not a coating, but rather an alloy of several elements. Stainless steel has the advantage over other metals of being resistant to corrosion and rusting which is what makes it favored over other materials.

Stainless steel can be found in the home as cutlery and tableware, sinks, ovens, barbeques and as gardening equipment. It can be found in the town as bus shelters, phone booths, building facades, elevators, escalators, and subway stations and trains. Stainless steel is used in industry as pharmaceutical manufacturing equipment, chemical tankers, water treatment plants, and as automotive and airplane components. (ISSF, 2007)

2.2: Nickel and Chromium Resources

Nickel and chromium are important elements involved in the production of stainless steel. These elements are located in mines all over the world. Depending on the location and amount of each material, it may be difficult for some countries to obtain

these elements.

There is a large supply of chromium throughout the globe, but mines are only located in a few countries. There are three major suppliers of chromium: India, Kazakhstan, and South Africa. They are all located relatively close to each other. A table of these countries' production and reserve base can be found below:

Country	Mine Production (tons)		Reserves (tons)	Reserves base (tons)
	2004	2005	(shipping grade)	
United States	-	-	-	-
India	2,950,000	3,000,000	25,000,000	57,000,000
Kazakhstan	3,270,000	3,300,000	290,000,000	470,000,000
South Africa	7,630,000	8,000,000	160,000,000	270,000,000
Other Countries	3,620,000	3,700,000	NA	NA
World Total (rounded)	17,500,000	18,000,000	NA	NA

Table 1 World Mine Production, Reserves and Reserve Base by Region (USGS, 2007)

South Africa is the leading producer of chromium even though Kazakhstan has a larger amount on reserves. These two countries account for more than 95% of the world's total supply of chromium.

Nickel mines are also located globally, but they do not contain nearly as much weight as chromium. There are a several countries that supply a large amount of nickel, but Russia produces the most substantial amount.

Country	Mine Production		Reserves	Reserve base
	2004	2005		
United States	-	-	-	-
Australia	178,000	210,000	22,000,000	27,000,000
Botswana	33,000	37,100	490,000	920,000
Brazil	45,200	46,000	4,500,000	8,300,000
Canada	187,000	196,000	4,900,000	15,000,000
China	64,000	71,000	1,100,000	7,600,000
Colombia	75,000	72,500	830,000	1,100,000
Cuba	72,400	75,000	5,600,000	23,000,000
Dominican Republic	47,000	47,000	720,000	1,000,000
Greece	21,700	22,100	490,000	900,000
Indonesia	133,000	140,000	3,200,000	13,000,000
New Caledonia	118,000	122,000	4,400,000	12,000,000
Philippines	17,000	22,000	940,000	5,200,000
Russia	315,000	315,000	6,600,000	9,200,000
South Africa	39,900	41,700	3,700,000	12,000,000
Venezuela	20,500	22,000	560,000	630,000
Zimbabwe	9,520	9,800	15,000	260,000
Other Countries	11,000	26,000	2,100,000	5,900,000
World Total (rounded)	1,400,000	1,500,000	62,000,000	140,000,000

Table 2 World Mine Production, Reserves, and Reserve Base by Country (USGS, 2007)

Although Russia has the largest production of nickel than any other country, Australia has a much greater amount on reserves. There is more nickel in the world than indicated in this table, but this amount is nearly impossible to mine, as it is located below the ocean floor.

The amount of chromium in stainless steel is much greater than that of nickel, but the price of nickel makes it more costly overall than chromium in the production process. The price of nickel is substantially larger than chromium because there is less nickel available to mine. As the cost of nickel is so high, the price of stainless steel is directly affected by the price of nickel.

The price of chromium is not openly traded so there is no available information

on it (USGS, 2007). However, ferrochrome is openly traded and it is used in the production of stainless steel.

Ferrochrome (average annual price)	
2002	\$.30/lb
2003	\$.47/lb
2004	\$.68/lb
2005	\$.73/lb

Table 3 Average Annual Price of Ferrochrome (Estainlesssteel, 2007)

The price of ferrochrome has more than doubled in the past four years. The increase in the price of chromium is still less than the increase in the price of nickel.

Nickel prices have been rising over the past five years, which directly affects the price of stainless steel. The one year and five year increase in nickel prices is demonstrated in the figures below.

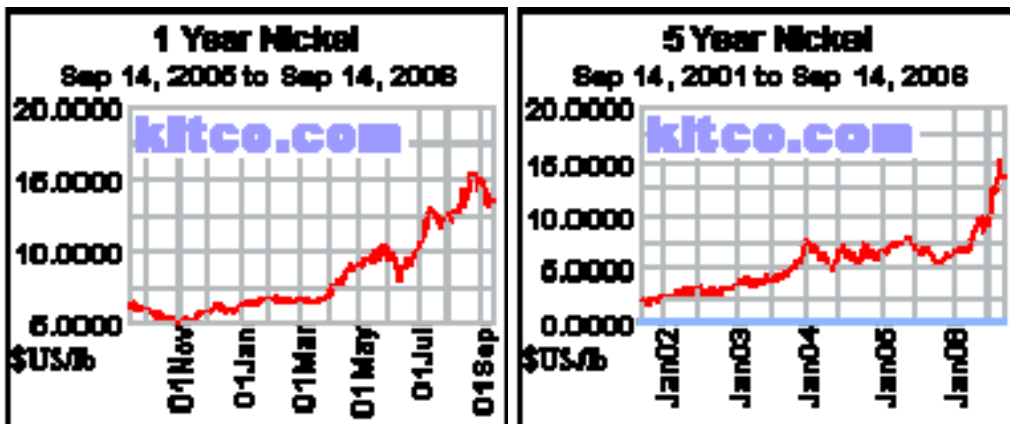


Figure 1 One-Year Nickel Prices

Figure 2 Five-Year Nickel Prices

Nickel tripled in price from 2002 to 2004 and then remained at approximately the same price until 2005. Since the beginning of 2006, the price has doubled yet again.

From 2002 to 2006, the price of nickel has sextupled which is why it is important to recycle as much material as possible.

Nickel prices have fluctuated since the industrial age with several key factors causing its rise and fall. Whenever a war occurs in which superpowers get involved, the price of nickel rises. A strike of major mining facilities, such as Inco, also causes the price to go up, but once the strike is over there is a surplus of nickel so the price drops. Large earthquakes and other natural disasters, where buildings are destroyed, cause an increase in nickel because these locations need to be rebuilt after such an event and they tend to use stainless steel in the rebuilding process. This causes a sharp spike in demand. The current reason for the increase in the price of nickel is that China has been using stainless steel more than any other country, which is causing a nickel deficit market.

2.3: Chip Producing Processes - Grinding

Grinding is the process of using an abrasive to finish a surface through material removal. “An abrasive is small, hard particle having sharp edges and an irregular shape...”(Kalpakjian, 2006) and grinding wheels are composed of abrasive material bonded to each other, usually in the form of a wheel or disc, but can be cup shaped, flared, have a depressed center, etc.



Figure 3 BZZ Grinding Wheel

The key to an abrasive wheel is the grain size. Larger grains will remove more material and leave a coarse finish, whereas finer grains will do the opposite, and leave a smoother finish.

In the case where material removal is desired, “undeformed chip thickness is relatively large and wheel wear is so rapid it is not necessary to periodically dress the wheel to remove wear flats and metal adhering to the tool face” (Shaw 1990). Dressing the wheel would be the process of wearing the wheel flat and making sure it can perform its job properly.

However, in the case where smoothness is desired for the final product, “wheels must be periodically dressed to provide sharp cutting edges that are properly arranged and free of adhering metal” (Shaw 1990). By paying closer attention to the grinding wheel, a more desirable result is much more likely to occur.



Figure 4 Grinding Process

One major advantage grinding wheels have over cutting tools is their ability to self-sharpen. When normal cutting tools are worn down, they become continually less useful. When a grinding wheel is worn down, however, the layer that remains should be just as sharp and just as useful as the first layer.

2.4: Chip Recycling Processes

In this section, we will review the processes that make up recycling, beginning with the immediate steps that come after the manufacturing processes. There are many different ways to recycle chips from a slurry of chips and coolant. The following sections will discuss these machines as well as the principles they rely on in order to work.

2.4.1: Settling Tank

A settling tank is usually the first piece of equipment encountered in the recycling

process, and is used to separate the majority of the larger, heavier chips from the coolant. The system is usually set up to allow the chips to settle for 3-5 minutes (*aware*). The primary function of a settling tank is to reduce chip load by removing the larger chips before they are carried by (drag) conveyor to the primary filter.

There is no media (filters, etc.) to be replaced or dispose, however it is not a true filtration device, as it has no way to separate small particles (the clarity of the metal removal fluid depends on the time spent settling and the weight of the chips) (*aware*). This is why it is used as a preliminary process in the separation itinerary. In addition, separating aluminum and grinding swarf in this manner is ineffective due to their tendency to remain suspended in the liquid.

2.4.2: Magnetic Separation

Magnetic separation is designed specifically to separate ferrous from non-ferrous material. Units are typically magnetic bars and plates that collect the ferrous material from the MRF (Organization Resources Counselors [ORC], 1999). Once built up, the ferrous material is typically scraped off (manually or automatically depending on the system). It is then carried of by a (screw or drag) conveyor. These separators can be found in Plate Magnet, Tube Magnet, Hump Magnet, and Magnetic Grid assemblies. Here are a few other types of magnetic separators.

2.4.2.1: Overband Magnets

Overband magnets are installed across a conveyor belt carrying the material or inline over the head pulley (Master Magnets LTD, 2006). They are used primarily in the

quarrying and recycling industry to protect, clean, and separate materials. Automatic models discharge ferrous materials through a conveyor belt or vibratory feeder (Magnetix, 2006).

2.4.2.2: Drum Magnets

Drum magnets are used when there is a larger volume flow rate of material to be separated, as they have a larger effective surface area; they are also used when the separation process is too abrasive for overband magnetic separators (Master Magnets LTD, 2006). They can be found in both the electro-magnetic and permanent magnet varieties. The electro-magnetic versions of this product are for larger scale operations (e.g. car shredding plants), while those utilizing permanent magnets focus on smaller scale applications, such as agriculture.



Figure 5 Drum Magnet

Most magnetic drum separators work off of the same principals, with a strong 180 degree stationary magnet with a shell, covers (made of a material such as Manganese), that revolve around it (Master Magnets LTD, 2006). The drum magnet's poles (the number and type of which vary by model) attract the ferrous material to the cover while allowing the non-ferrous material to free fall. The heavy-duty models of these types of

drums are called Fragmentizer Drums and are used at times to separate municipal wastes (Global Equipment Marketing Magnetics Division [GEM], 2006).

A specific type of magnetic drum used in the recycling process is known as a Totally Enclosed Permanent Drum (TEPD). The drum specializes in products that are fine and freedom from external contamination is desired (Master Magnets LTD, 2006) (read: swarf separation).

Another available model of is the Wet Drum Separator. These are used in iron ore concentration, magnetic media recovery, and solids carried in liquid suspension (Ohio Magnets, 2006). They are mainly used in dense media plants (Master Magnets LTD, 2006). This type of drum is available in three different designs for different purposes; counter flow, counter-current, and concurrent applications are available.

2.4.2.3: Eddy Current Separators

Included for the sake of encompassing all types of magnetic separators, Eddy Current Separators are used to separate ferrous material, non-ferrous material, and non-metallic material into separate containers (Master Magnets LTD, 2006). They are used mainly in applications such as can sorting. They are not meant to deal with liquid mediums or semi-liquid mediums such as swarf.



Figure 6 Eddy Current Separator

2.4.2.4: Suspension Magnets

Suspension magnets are, as is their namesake, suspended over conveyor belts to remove occasional tramp iron (Master Magnets LTD, 2006). They are specifically designed to do so and as such do not have a large place in recycling from machining or grinding processes.



Figure 7 Suspension Magnet System

2.4.2.5: Pulley Magnets

Magnetic pulley separators are installed as replacement head pulley with a 360-degree magnetic field to ensure the ferrous material is carried beyond the centerline (Master Magnets LTD, 2006). A diverter plate behind the pulley sloughs off the ferrous material from the stream. Alternatively, the magnet can work in a 180-degree field and discharge can be caused by an air gap (Storch, 2006).

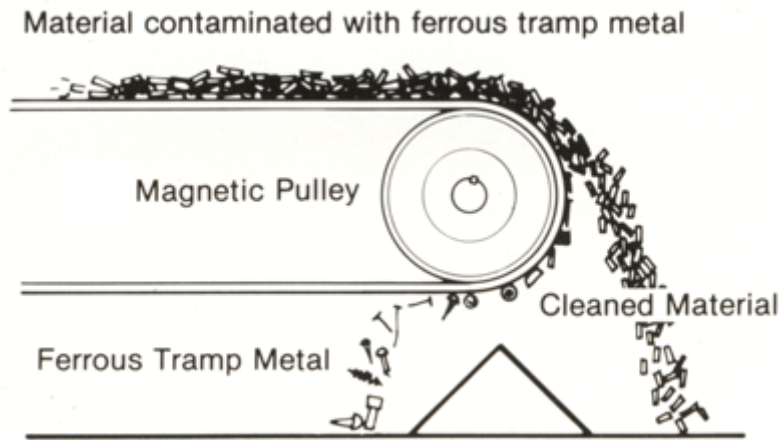


Figure 8 Pulley Magnet System

Magnets have an advantage over other forms of separation as they, much like settling tanks, have no media (such as filters) to change or discard, thus reducing maintenance costs. However, it will not remove non-ferrous materials and is ineffective with grinding swarf (ORC, 1999). In addition, magnetic separation typically requires a low flow rate.

2.4.3: Cyclonic Separation

Cyclonic separation can be found in two different setups: with and without moving parts. In the method without moving parts, the swarf is directed into a conic bowl at high velocity, which causes it to swirl (ORC, 1999). The centrifugal force and back pressure created by this motion causes the solid to move outward and downward respectively. It is then discharged through an underflow into the dirty tank. The MRF remains in the center as a spinning column and leaves through the overflow into a tank with clean MRF. This method has the advantage of having no moving parts or replaceable media. However it suffers the downfalls of being high maintenance,

necessitating two pumps (for clean MRF and “dirty” MRF), having a limited flow rate affecting the piping system, and quality is not consistent. Also, taking note of the separation method (where the solids pump back into the “dirty tank”), this separation method is used primarily for coolant recycling and not recovering the solid waste.



Figure 9 Cyclonic Separator

The second method (with a spinning bowl, also called “wringers”) can be found in a few different positional setups. There are vertical, diagonal-shaft, and horizontal versions available. However, much of the underlying principals driving their operation are the same. The wet chips are fed into the bowl, and as the bowl spins, the swarf moves towards the “top” of the bowl (the wider part of the conical shape). The fluids are forced through a screen or filter of some kind by the centrifugal force and reused in grinding processes (National Conveyors Company, 2006). The chips, now dry, are expelled from the “wringer” either by force of gravity or air discharge (Prabb, 2006). This system has many advantages. Like the previous process, it has no medium to replace or dispose of. The quality of the removed MRF is high, and there is up to 98% recovery in some models. The process is fully automated, and the machines require little maintenance (mostly to prevent clogging of inlet/outlet tubes) (Prabb, 2006).

2.4.4: Dissolved Air Separation

In this process, compressed air is pressed into the MRF, forming bubbles, which provide a large surface area (ORC, 1999). The surface tension attracts the solids and tramp oil and they are carried to the surface, which is then skimmed by a wiper blade.

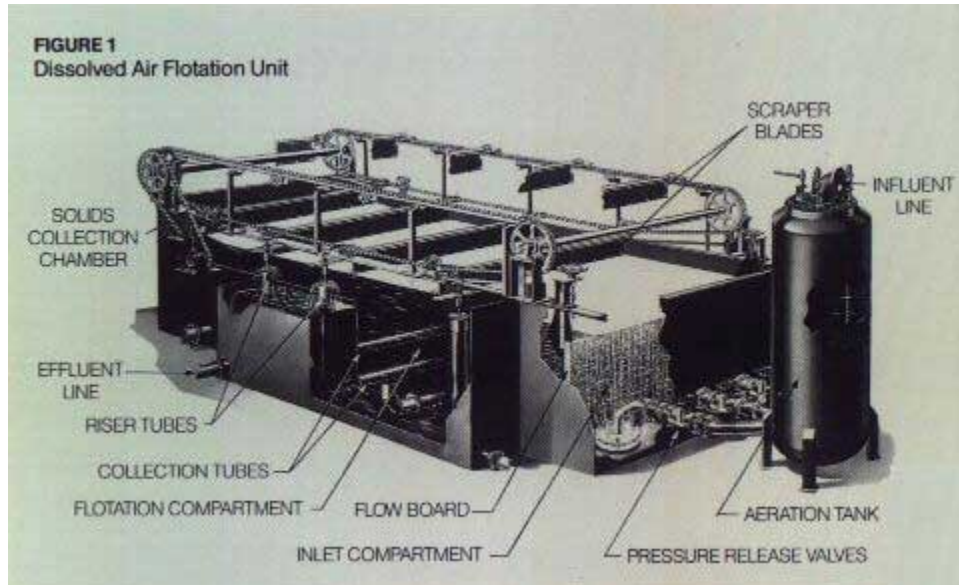


Figure 10 Dissolved Air Separation Unit

As with the other four, this requires no replaceable media. In addition, it works on very fine particles, meaning it is useful for the separation of precision grinding swarf (ORC, 1999). As mentioned above, tramp oil is also removed from the MRF increasing its quality. However, this method requires a lot of floor space in relation to the amount of MRF it processes (25 GPM takes roughly 6.5' x 6.5') and a compressed air system is necessary.

2.4.5: Briquetting

In this process, a slurry comprised of chips and coolant is feed into the machine by means of a conveyor belt. A hydraulic compressing cylinder then compresses the slurry. Alternatively, a pneumatic compression system could be used, but this will result

in less compression force. The compression forces the coolant out of the slurry, resulting in a briquette of stainless steel chips. This operation typically removes ninety-eight percent of the coolant from the chips. It allows a large volume of chips to be easily transported due to the small size of the briquettes.



Figure 11 Briquetter

There are some briquetters that have a precompression chamber, which uses a slightly less powerful hydraulic compressing cylinder. This allows the main compression cylinder to further compress the chips into a smaller briquettes. Having a precompression chamber also reclaims more coolant, up to ninety-nine percent.

It is beneficial for companies to utilize a briquetter when they have a low volume of space that can be used to store chip waste. Being able to store more chips, in the compressed briquette form means that a company can produce more chips, which means they are producing more product. This increase in production will also cause an increase in profit for the company.

2.5 Scrap Economics

Steel is America's most recycled material. The decision to recycle is an economic

one, as industry recognizes scrap to be a valuable resource for creating new product. Thus, companies have been reusing steel for over two decades. The process itself has a well-developed infrastructure.

In 2001, the North America steel industry recycled approximately 65% of all steel produced. Old steel has become a necessity to create new materials do to these factors as well as environmental and economic benefits. An example of this is the automotive industry, which in 1997 recycled enough old automobiles to manufacture 13 million new vehicles. There are many sources of scrap material, but they will not be reviewed in detail as this project is focusing on material recovered from dry grinding processes.

Steel's metallic properties rendering it recyclable has created an economic environment of reuse, where any existing steel product could potentially be used to create another in the future. The grinding chips at the focus of this study could very well be used to create a food can, utensils, an automobile, or an appliance. This flexibility is due in part to the "open loop" recycling environment, where scrap is usually delivered to the nearest plant despite its old uses. This allows for quick turnaround time and an indefinite amount of possible iterations and life cycles for a given volume of the metal.

2.5.1: Steel Scrap End Markets

The major end market for steel scrap is also the beginning of the life cycle: the steel mill. There were over 120 steel mills in 2001. Steel mills generally come in two varieties: Basic Oxygen Furnaces (BOFs) and Electric Arc Furnaces (EAFs). In general, these foundries use 30-40% purchased scrap (as well as "home" scrap, scrap created by the steel making process, which in today's industry is minimal).

2.5.1.1: Basic Oxygen Furnace

Basic Oxygen Furnaces accounted for more roughly 60% of steel production in 2001. The process requires a minimum of 25% scrap material to complete. The name of the process originates from the oxygen that is delivered to the mix (molten iron and scrap steel) in a high-speed blast to increase heat. The oxygen is delivered via a “lance” inserted through a funnel-shaped opening in the top of the furnace. A sustained chemical reaction occurs between the oxygen and carbon in the iron, creating the extreme heat necessary to create steel. This heating period takes around 45 minutes. The characteristic typically desired from these furnaces is ductility, and steel from these plants can be found in appliances, residential construction, and cans. They usually make flat and/or heavy products and “very clean” (minimal impurities) carbon steel (UN 1993).

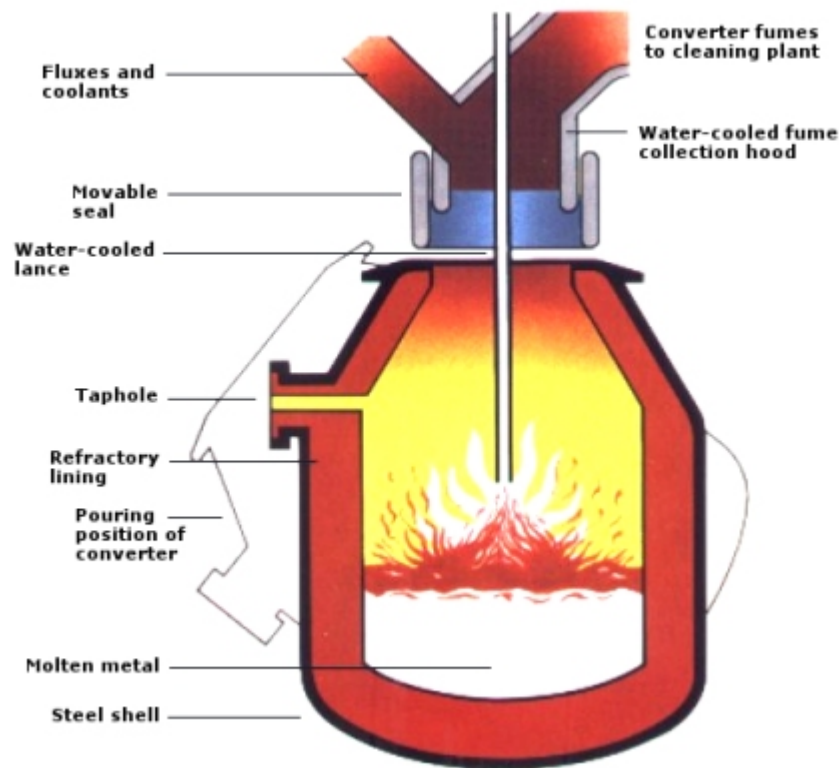


Figure 12 Diagram of Basic Oxygen Furnace

The primary metal used besides scrap in BOFs is pig iron. The usual production

capacity of a BOF is 1-10 Mt/yr (UN 1993). The furnaces themselves have a very inflexible operation. There is a need to operate the furnace extremely steadily for a good yield and desired heat, and there is a need to feed the converter directly to hot metal, which creates a dependency on the blast furnace.

2.5.1.2: Electric Arc Furnace

As opposed to the Basic Oxygen Furnace, which combines new raw material (molten iron ore) with steel scrap, EAFs can use nearly 100% recycled material (although some scrap alternatives have been developed to be used in growing proportions). The electric charge enters through the roof, where three large electrodes are lowered to melt the material. The usual desired trait of these steels is strength. The average ratio of scrap to produced steel in 1995 globally was 1,000 Kg scrap/t of steel, and numbers up to 1,100 Kg/t were typical (UN 1995). EAFs have expanded worldwide in recent history compared to BOFs and consume the most amount of steel scrap globally.

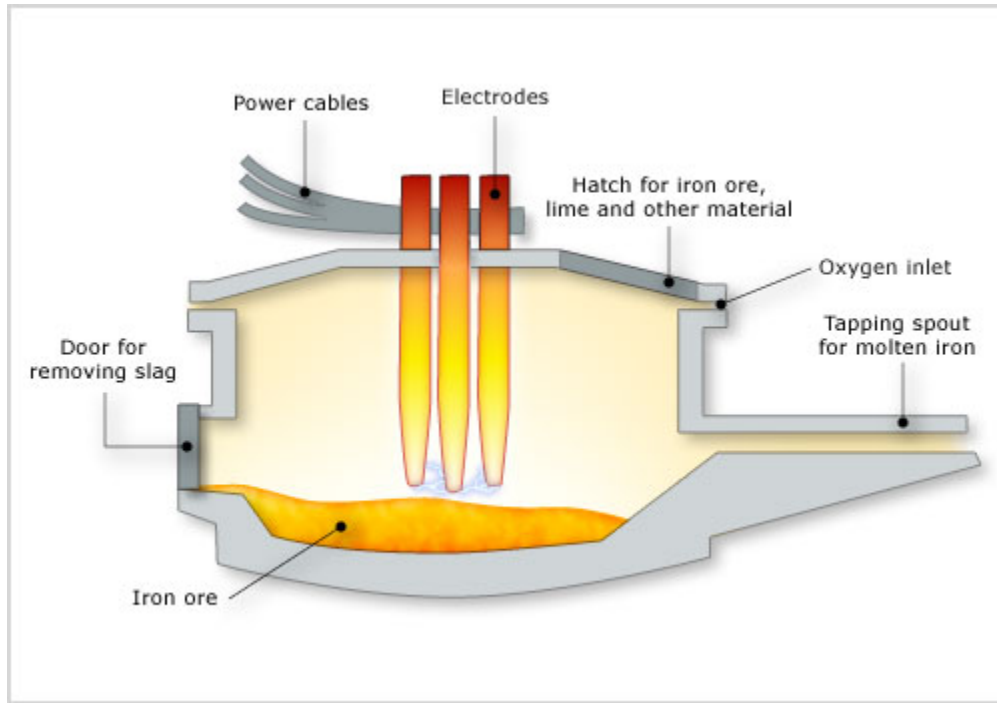


Figure 13 Diagram of Electric Arc Furnace

EAFs' usual production capacity is 0.1-1 Mt/yr (UN 1993), which is ten times less than that of the BOF. However, EAFs are much more flexible, as they can be stopped and started whenever necessary.

An advantage EAFs have over BOFs financially is the large investment reduction (UN 1993). As it is a short process, capital investment and depreciation are lower due to the smaller amount of necessary equipment to complete the process. The energy costs of EAFs are generally less of BOFs as well.

2.5.2: Types of Scrap

There are three types of steel scrap. One is mill scrap. This is the scrap created in the steelmaking process. Continued improvements in the efficiency of steelmaking have lowered this number to minuscule levels. It is also called "home" scrap, and is

preconsumer. Steel mills were once the chief suppliers of their own scrap but are now dependent on outside sources.

Manufacturing scrap, also known as “prompt” scrap (also preconsumer), is created during the manufacturing processes that lead to the end product. The grinding chips created by the BZZ rough surface finishing process is manufacturing scrap. Two variables define the availability of prompt scrap: the production rates of steel products and the efficiency of the manufacturing process (UN 1995). Industry has made great efforts to reduce the amount of scrap created by these processes. Therefore, overall quantitative increases are only found in developing countries, especially in Asia.

Post consumer scrap is steel materials collected at the end of their life cycle. Examples include appliances, automobiles, cans, and structural steel. This type of scrap is the only type that has increasing quantitative availability (UN 1995).

2.5.3: Scrap and Iron Ore Price Variation Comparison

With Iron Ore, there is little to no fluctuation price wise, and prices are generally set annually (UN 1993). These changes are limited to changes in economics of the steel industry.

Scrap price fluctuations vary wildly of the short term. Prices can change in as little time as one week, and fluctuating from month to month is typical (UN 1993). The year-to-year fluctuations depend greatly on these short-term changes and are of course influenced by the economic environment of the area.

This is due to the suppliers of both materials. Iron Ore is produced by a small amount of large mines and plants and distributed to a larger and larger number of

consumers; Iron ore is received by a very large number of smaller users (UN 1993). Scrap is distributed to plants by ferrous scrap processors, who prepare the scrap to furnace specifications and ship the material. In 2001, there were 1500 of these businesses in North America. Consolidation of these extremely small flows creates steel mill stock.

Scrap is far more adaptable to the local economic situation due to its quick fluctuation rates (UN 1993). There have been times in the US that one ton of scrap was cheaper than a ton of pellets of oxidized iron.

2.5.4: Scrap Quality and its Effects

Steel quality is a broad term that covers a wide range of factors including its physical properties, manufacturing/fabrication workmanship, technical properties, and the required chemical composition of the steel (UN 1992). Over time, demand has risen for higher and higher quality steels. Industry has kept pace with a vast amount of technological progress near the end of the 20th century. New metallurgical processes, online process control, and the introduction of new furnaces such as the EAF and BOF have allowed the industry to match consumer demands. This is done by tightly controlling the amount of impurities entering the steel at the steelmaking stage.

The increased demand for higher quality was instigated mainly because of CAD/CAM integrated manufacturing processes (UN 1992). These programs worked on the principals of homogenous composition and structure of steel. Uniformity between steel made in the same heat and various heats was also necessary.

Steel cleanliness is measured by a volume's impurity content. Any element not intentionally introduced into the steelmaking process is considered an impurity (also

known as “tramp elements”) (UN 1992). The reason impurity content is relevant is that even small amounts can affect the intended properties of the steel negatively.

Necessary cleanness depends on the desired quality of steel. For long carbon steel products, they tend to be less stringent than flat products used in important applications. These very strict classifications are also known as “clean steels” (UN 1992). Different classifications are used; the one that will be discussed is classification through the quality of the raw materials.

Prompt and post consumer scrap is the primary source of tramp elements (UN 1992). However, the steelmakers may adjust the quality based on the percentage of tramp elements that can be removed through metallurgical processes in the refinement phase. In the process of recovery, non-ferrous materials are difficult if not impossible to remove. This necessitates careful selection of scrap to conform to consumer standards. In order to control the level of tramp elements in the steel tramp content in the raw materials used in the production of steel must be known. Typical tramp element percentages for various raw materials are listed below in table 2.4.

Raw Material	Sum of Cu, Sn, Ni, Cr, and Mo Percentages
Directly-Reduced Iron	0.02
Pig Iron	0.06
Scrap: No. 1 Factory Bundles	0.13
Scrap: Bull shelling	0.13
Scrap: No. 1 Heavy Melting	0.2
Scrap: Shredded Auto	0.51
Scrap: No. 2 Heavy Melting	0.73

Table 4 Impurity Percentages in Various Steeling Making Raw Materials as of 1992

Another available option was to take advantage of non-ferrous metals in scrap to produce alloys, as they cannot be removed (UN 1995). For example, nickel and chromium are necessary components of the steel covered in this project, stainless steel.

Element	Scrap	Pig-Iron and Pre-Reduced Ore	Consequences
Fe	92-98%	92-96%	Useful Component
Residual Oxygen	Generally low; -3 %	0 in Pig Iron; 1-4% in DRI & HBI	Disappear During Steelmaking Process
Carbon	0-1%	-5% in pig iron; 0-3% in DRI & HBI	
Gangue	Can reach or exceed 1-3%	0 in Pig Iron; 2-5% in DRI, HBI	Disappear in Slag
Metalloids (P, S, etc.)	Generally low; May exceed 0.1%	Generally Low; 0.01%-0.50%	May enter steel depending on process
Dissolved Gases (O, N, etc.)	Variable	Absent	
Metals <u>more oxidizable</u> than Fe (Cr, Zn, etc.)	Variable; May exceed 0.1-0.2%	Generally Traces	May enter lag or be eliminated
Metals <u>less oxidizable</u> than Fe (Cu, Ni, Mo, etc.)	Variable; May exceed 0.2-0.3%	Generally Traces	Enters steel

Table 5 Comparison of Scrap and Primary Metal Components

2.6: Environmental Aspects of Recycling Grinding Chips

Chips created during the grinding process of making stainless steel have an impact on the environment. Discarding these chips has a negative impact on the environment as well as a waste of time and money to the manufacturer. Dry chips from the BZZ process have less of an impact than chips discarded with coolant. Although the natural resources involved in the discard of stainless steel chips are not renewable, they are reusable. Recycling any of these chips would lessen the effect they have on our

environment.

Coolants that have been discarded from the production of steel have greater consequences towards the environment than the dry chip processes. Coolants have to be modified in order to create a more environmentally friendly waste from chips generated from the steel process. There are five different ways of reducing the harmful impacts to the environment:

1. Modifying the composition of the coolant by:

Application of composition without oil.

Using synthetic materials.

Preference for natural materials.

Application of biologically breaking down materials.

Application of materials with significantly longer tool life.

2. Reducing the amount of coolant by:

Programmed feeding of coolant.

Optimized dosing.

Supervised conduction.

3. Minimizing the amount of liquid (minimal cooling) by:

Using less than 50 ml h⁻¹ of liquids.

Inner conduction through the tool.

Externally controlled conduction with special dosing equipment.

Application of liquid mixed with air.

4. Application of coolant not in liquid state by:

Cooling with compressed air or with cold gas.

Cooling with solid coolant.

Using impregnated tools.

5. Dry machining

(Mamalis, Kundrak, Gyani)

There are several ways to reduce the effect of coolant on the environment. The best solution is to eradicate the coolant altogether by using a dry machining process such as the BZZ.

Scrap metal steel will always have an environmental impact regardless of if it has coolant associated with it. The main environmental impacts are on air, on water, from waste and by-products, and CO₂ production. These impacts vary depending on the unit used to process the steel as illustrated below:

Unit	Main Impacts				
	On air	On water	From waste and by-products	On CO ₂ production	Other
Sintering	XXX	-	-	X	
Pelletizing	XX	-	-	-	
Coking	XXX	XXX	XX	XXX	

Blast Furnace	X	X	X	XXX	
Oxygen steelmaking shop	XX	X	X	-	
Electric steelmaking shop	XX	X	X	-	Noise
Secondary metallurgy	X	X	-	-	
Continuous caster	-	-	-	-	
Hot rolling	-	X	-	-	
Cold rolling	-	XX	X	-	
Finishing	-	XX	X	-	

Table 6 Main Environmental Impacts of Steelmaking Units or Operation

XXX indicates very substantial impact

XX indicates substantial impact

X indicates limited impact

The coking unit produces the most harmful environmental effects compared to any other unit. Continuous caster has no environmental influences at all so this unit would be the best option for the production of recycled steel.

Discarding chips is harmful to the environment regardless of if they are dry or not. Not all the chips that are recycled end up in landfills where they lose their potential to be reused. Recycling of these chips will actually cost less than disposing them into a landfill. The operating cost of a manufacturer will decrease if they use recycled chips. Less operating costs means less greenhouse gases will be produced by the manufacturer because less fossil fuels are burned. For instance, every pound of recycled steel has enough energy to light a 60-watt light bulb for 26 hours. The energy saved from recycling the many tons of material wasted in landfills will make it worthwhile for a manufacture to recycle. (recycling-guide, 2007).

3: Methodology

This section will detail the methods that we used to complete this project, and the justification for using each method. Naturally when presented with a problem there is more than one way to approach it, and for the objectives we set, there was a definitive way, which was the best way of approaching each goal.

3.1: *In-depth literature research*

- Special attention to recent texts
- Journal articles
- Using the metals abstract
- Websites
 - World Bureau of Metal Statistics
 - Economic
 - Environmental

Literature research has been helpful in finding information for general topics not specific to the BZZ or dry grinding processes, especially with the recycling of stainless steel chips in-house. Information on the steel industry, steel scrap (economics, steelmaking, recycling of, etc.), and grinding processes in general was available. However, these are all satellite topics to our main focus, which is how the manufacturers process these steel chips.

3.2: *Data Analysis*

In this stage of the game, all the information gathered are being analyze. The breakdown analyzing categories are BZZ production, chip properties, steel market, and

recycling process.

3.2.1: BZZ Process Analysis

The BZZ process is a process to remove the surface impurities of stainless steel billets. The process removes roughly 0.5% to 1.5% of the total material. Chips are produced and accumulated at a rate of 200-500 kg/hr. The process operates at room temperature and can rise up to 800 degree Celsius.

3.2.2: Chip Properties Analysis

The BZZ process produces stainless steel chip and the BZZ wheel materials itself. The commonly used chips are grade 304 and 409. Grade 304 is more expensive than 409 because it is more durable, harder to produce and probably it is a non-ferrous material.

The BZZ wheel is made of several materials, which include brown fuse alumina, white fuse alumina, and alumina zirconia. These materials are the main materials that are used to remove stainless steel material. There is almost bonding material that held the grinding materials together.

3.2.3: Stainless Steel Market Analysis

Stainless steel market analysis may provide useful information on the economics of the buying/selling price and steel scrap price. Market trends and the profitability of recycling can then be assessed. It is important to note that economic trends must be examined globally rather than just in the United States.

3.3: Survey Industry Sectors Applicable to Project

In order to gather information for this project we needed to first determine which industries would be applicable and then contact them for information. This section illustrates how we did this.

3.3.1: Grinding Industry

As general literature lacks the information we need of BZZ grinding and their recycling processes, we will need to ask the manufacturers themselves how they deal with grinding chips and their recycling.

3.3.2: Manufacturers of recycling machines

If we can discover the equipment involved in the procedure of recycling the dry grinding chips, we will survey the makers of this equipment to get a better idea of current state of the art techniques. This is necessary to avoid redundancy in making recommendations when research into the matter is concluded.

3.3.3: Metal recycling industry

As was discovered during literary research, there are many ferrous scrap handlers and processors in the United States. Contact these handlers, who deal in processing and transporting the scrap before being used in steel mills, will give us an insight in how the chips must be prepared to be reused in the steelmaking process. If data from the sectors mentioned above is difficult to come by, they may also act as a reserve source of information about processes that occur before reaching them.

3.3.4: Steel Mills

Most information concerning steel mills can be found in literary research concerning the steelmaking process and how scrap is used. However, surveying the plants may confirm how many plants use BOF or EAF furnaces, how much scrap they use, and the intricacies of using scrap with non-ferrous impurities (such as stainless steel scrap) to recreate alloys with elements the same type as the tramp elements.

3.3.5: Dumps and Waste Sites

If within the scope of our project, we may confer with waste disposal agencies and sites to ascertain the amount of heavy metal waste is accumulated and if possible, get as specific as stainless steel content.

3.4: Synthesis

The data analysis provides detailed information that is useful for further assessment. That information is used and integrates into a cost/revenue formula using Excel and MathCAD software to generate a predictable outcome model for the whole recycling process. A cost structure is also constructed from the provided information to compare between machine cost and the process cost throughout the whole recycling process. The result for the cost structure of steelmaking process and recycling process will be mentioned in the next section for the results and outcome.

A structure of recycling process for stainless steel chip is shown in figure 3. The structure lists the break down of the recycling process into stages starting at the instant when the chip fell on the floor. The first stage in the recycling process is collection of

chips, which might or might not include coolant. If there is coolant, then the chip process through “solid and liquid separation” stage. Then the stainless steel chip is separates from the wheel materials and transports to stainless steel making plant.

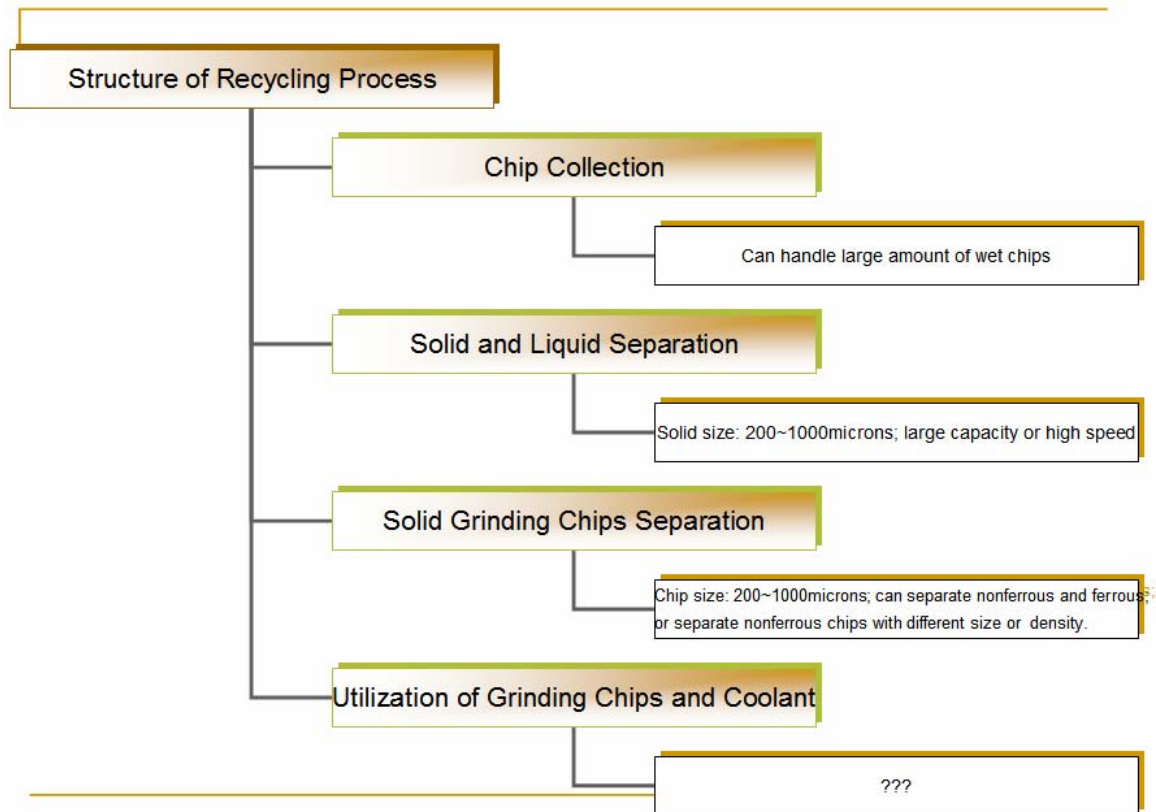


Figure 14 Recycling Process

3.5: Cost Model

The cost model then provides the total processes cost, initial investment, and the differences between different methods. Through the cost model, methods can be compares and choose the most efficient method that is work best for certain situation.

3.6: New Model

One issue that arises through the analysis of chip recycling process, there is no machine that is currently available to separate small size non-ferrous stainless steel from non-ferrous material of the wheel. Therefore, a new method to separate different non-ferrous materials is necessary to recycling non-ferrous stainless steel such as 304. That is why a new methodology in non-ferrous materials separation is introduces. Later in new method section, a new idea to separate non-ferrous materials, which might solves the problem of non-ferrous materials separation.

4: Results

This section will outline the results from the research we have completed. We will begin by illustrating the feasibility of recycling methods for chip and slurry mixtures, and then talk about the cost structure we have constructed.

4.1: Feasibility of Methods

There are four methodologies for separating 304 chips from abrasive grit .The vibration of separation is one of the four methodologies. Whether the vibration of separation is suitable for this recycling process, the result can be found out from the following analysis. These methods are outlined in the table below.

Methodology	Principle or Property	Product
Vibration of Separation	Use vibration to separate different proportion of chips	Not ready
Melted Separation	According to the different melting points, melt one part on specific melting temperature, then separate the other parts (Remarks 1)	Not ready
Magnetic Separation	1.Magnetize Non-magnetic objects, then use magnetic tools to separate chips (Remarks 2) 2.Use the magnetic separator to collect the ferrous chips as they pass through the device (Remarks 3)	1.Eddy Current System or Not 2.Not ready

Table 7 Separation Methods Outline

4.1.1: Vibration Separation

If different things are mixed together, vibration separation can be used to separate them. As a result of the different density or size, they will bear different forces in the vibration process. For example, if we vibrate the chips up and down, the heavy chips get down for the gravitational force and the light chips get up. If we treat the chips with circumference force, the heavy or big chips will go the edge of the circle. This method is often used in the ferrotitanium industry and is described here.

Ferrotitanium is metallurgical alloy used to make steel more ductile, more readily formed into thinner automotive body panels or appliance cabinets. However, ferrotitanium is an abrasive material that can tear up process equipment in the plants where it is produced.

Global Titanium Inc. is one of the world's top producers of ferrotitanium, supplying it in granular form for shipment to steelmakers, but the product was literally tearing holes in the screen separator used to classify the granules by size. The problem was solved after Global installed a new stainless steel separator made by Kasson Corp.

Global Titanium buys titanium scrap and blends it with iron to make ferrotitanium. The materials are charged to an induction furnace where they react to form ferrotitanium at an average temperature of about 2,650F. The metal is poured into molds to form 5*5-ft ingots (1.52*1.52M), about 6in. thick and weighing 1,900-2,000 lb (862-907kg).



Figure 15 Ferrotitanium process 1

In the above picture, Ferrotitanium is dropped onto the separator's coarse top screen. Smaller granules pass through the screen and larger ones migrate to the edge.



Figure 16 Ferrotitanium process 2

The above picture shows a view of the top of the separator shows how the larger ferrotitanium granules are removed through the port at the left side.

This is how the process works for ferrotitanium, but for the BZZ conditioning process, these are the results we found. We can find out that the BZZ chips' size and density is varying as well as the stainless steel's size and density is varying and this is shown in the table below.

	Chip Size	Density
BZZ	Small and varied	Varies from 2.8 to 3.5 g/cc
304	200~1000 microns and Varies	7.9g/cc
409	200~1000 microns and Varies	8.0~8.5g/cc

Table 8 BZZ Chip Size and Densities

We cannot find out the boundary of the weight or size for the mixture of stainless steel and BZZ chips. Thus the vibration of separation is not suitable for us to separate stainless steel and BZZ chips. Because of the varying size and weight of the stainless steel and BZZ chips, we cannot use this vibration of separator to finish the recycling process.

4.1.2: Separation by Melting

There are four methodologies for separating 304 chips from abrasive grit .The melted separation is one of the four methodologies. Whether the melted separation is suitable for this recycling process, the result can be found out from the following analysis. Because different substances are in different melting points, we can use the melting machine to melt part of them, and then the rest will be left. For example, if two kinds of things mix together and the melting points of them is very different, such as 300 and 1000, we can melt the matter of 300 and the matter of 1000 will stay in solid. Then we can separate the solid and liquid things.

To determine the melted separation system's suitability for separating grinding chips we used the following data:

- The melting point of 304 and 409 is nearly 1350C
- The room temperature of BZZ wheel is up to 950C

Using these data, we can make the following conclusions. The melted separation is not suitable to separate stainless steel chips from abrasive grit because of the melting points are too near. Secondly, if the temperature for stainless steel is over 1050~1100C, the composition of stainless steel will change because of this kind of heat treatment.

4.1.3: Eddy Current System

There are four methodologies for separating 304 chips from abrasive grit .Eddy current system is one of the four methodologies. Whether the eddy current system is suitable for this recycling process, the result can be found out from the following analysis.

An eddy current (also known as Foucault current) is an electrical phenomenon discovered by French physicist Leon Foucault in 1851. It is caused when a moving (or changing) magnetic field intersects a conductor, or vice-versa. The relative motion causes a circulating flow of electrons, or current, within the conductor. These circulating eddies of current create electromagnets with magnetic fields that oppose the effect of the applied magnetic field. The stronger the applied magnetic field, or greater the electrical conductivity of the conductor, or greater the relative velocity of motion, the greater the currents developed and the greater the opposing field.

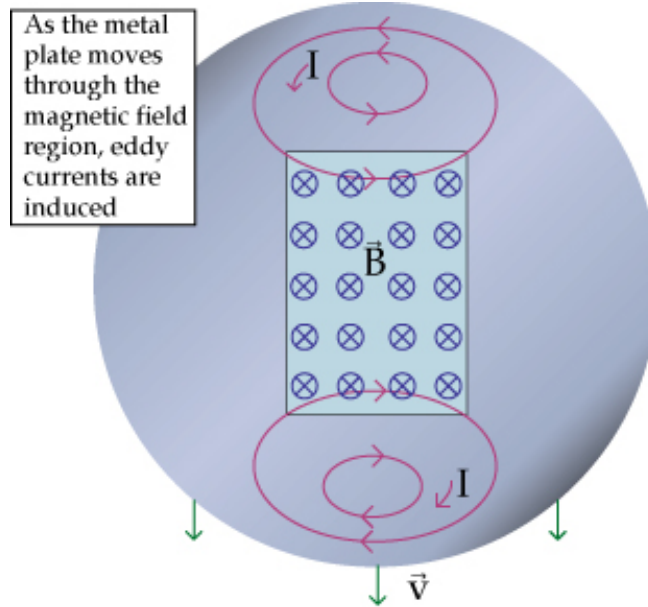


Figure 17 Eddy Current diagram

It is important to appreciate that eddy currents are created when a conductor moves across a constant, uniform magnetic field, as well as when a stationary conductor encounters a varying magnetic field. Both effects are present when a conductor moves through a varying magnetic field, as is the case at the top and bottom edges of the magnetized region shown in the diagram. Eddy currents will be present wherever the conducting object, which is moving, experiences a magnetic field, and not just at the boundaries.

The swirling current set up in the conductor is due to electrons experiencing a Lorentz force that is perpendicular to their motion. Hence, they veer to their right, or left, depending on the direction of the applied field and whether the strength of the field is increasing or declining. Lenz's law encapsulates the fact that the current swirls in such a way as to create an induced magnetic field that opposes the phenomenon that created it.

In the case of a constant, uniform applied field, the induced field will always be in the opposite direction. The same will be true when a varying external field is increasing in strength. However, when a varying field is falling in strength, the induced field will be in the same direction as that applied, in order to oppose the decline.

Eddy currents create losses through Joule heating. More accurately, eddy currents transform useful forms of energy, such as kinetic energy, into heat, which is generally much less useful. Hence, they reduce the efficiency of many devices that use changing magnetic fields, such as iron-core transformers and electric motors. They are minimized by selecting magnetic core materials that have low electrical conductivity or by using thin sheets of magnetic material, known as laminations. Electrons cannot cross the insulating gap between the laminations and so are unable to circulate on wide arcs. Charges gather at the lamination boundaries, in a process analogous to the Hall effect, producing electric fields that oppose any further accumulation of charge and hence suppressing the flow of eddy currents. The shorter the distance between adjacent laminations (the greater the number of laminations per unit area, perpendicular to the applied field), the greater the suppression of eddy currents is.

The loss of useful energy is not always undesirable, however, as there are some practical applications. One is in the brakes of some trains. During braking, the metal wheels are exposed to a magnetic field from an electromagnet, generating eddy currents in the wheels. The eddy currents meet resistance as they flow through the metal, thus dissipating energy as heat, and this acts to slow the wheels down. The faster the wheels are spinning, the stronger the effect, meaning that as the train slows the braking force is reduced, producing a smooth stopping motion.

If the powerful permanent magnets in the roller rotate at a high speed, there is a high electromagnetic induction originating in the surface. When the aluminum, copper, brass and magnesium (which is easily conductive) go through the magnetic field, they produce eddy current in themselves and then will be thrust forward. The effect between the roller's magnetic field and the eddy current, which is in the nonferrous metal, can be easily explained by this chart.

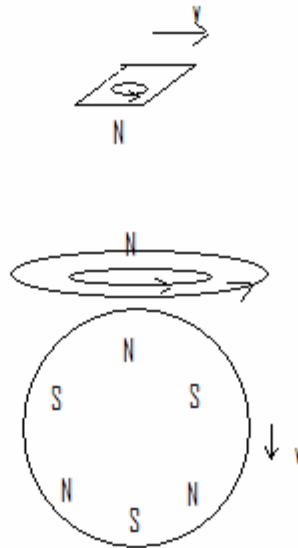


Figure 18 Eddy Current Magnetic Field Diagram

The magnetic field depends on two situations, which are:

1. The speed of magnetic field's alteration, this kind of change is caused by the speed of roller's rotation. The higher speed of the rotation, the more powerful the magnetic field is.

2. The primitive magnetic field of the roller; if the magnetic field of the roller is more powerful, the change of the magnetic fields is more effective.

To determine the effectiveness of this method, we first noted that the composition of grinding chips is as follows. Firstly, stainless steel ceramic: 70 wt%, Resin: 10 wt%. Secondly, stainless steel chips 304 and 409. Lastly, there are impurities, which need to be accounted for.

The eddy current system can produce eddy current in the metallic materials. We can find that there are many metallic materials in the mix chips, not only stainless chips but also other steel chips. If the mix chips go through the eddy current system for separating, the eddy current is originating in the stainless chips and other steel chips. Therefore, the magnetic field cannot separate them for the eddy current in both the stainless chips and other steel chips.

The carbon steels and specialty steels are ferrous chips, which can be attracted by the magnetic field. When these kinds of chips go through the eddy current system, they will be attracted by the magnetic field, which is produced by the rotating magnet roller, and then these chips will follow the roller that they can damage the machine.

It is also necessary to take into account the size of the grinding chips and abrasive chips, which are both the same as 200~1000 microns. A varying electric current flowing in a coil gives rise to a varying magnetic field. A nearby conductor resists the effect of the varying magnetic field, and this manifests it self by an eddy current flowing in a closed loop in the surface layer of the conductor so as to oppose the change causing a back electromotive force in the coil. The size of the chips is very small that they cannot produce electric current in themselves. The smallest size for producing eddy current is 5mm.

To conclude, the eddy current system includes magnetic rotors to produce varying magnetic field. Because of the ferrous chips, they will be attracted but not excluded by the magnetic field, and will damage the machines. There are two situations which we can use the current systems, the mix things only contain nonferrous metals and nonmetallic materials, also when the size of the nonferrous metals is no less than 5mm. Therefore, we cannot use the eddy current system to separate our grinding chips.

4.1.4: Magnetic Separation

There are four methodologies for separating 304,409 chips from abrasive grit .The magnetic separation is one of the four methodologies. Whether the magnetic separation is suitable for this recycling process, the result can be found out from the following analysis. As product passes over the head pulley, non-ferrous material is discharged in a normal trajectory. Ferrous metal is attracted to the pulley and remains on the belt until the belt moves away from the pulley — falling clear of the product stream.

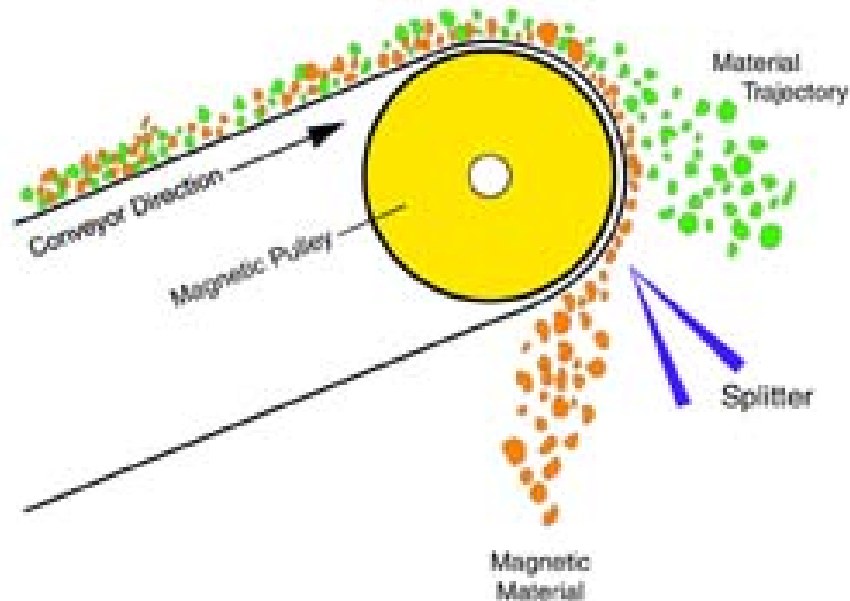


Figure 19 Magnetic Separation Diagram

Ferrous material can be attracted by magnet or magnetic filed. With the increase of magnetic power, the attractive force will become more powerful and can attract more ferrous materials. The compositions of grinding chips are; ceramic: 70 wt%, Resin: 10 wt%, stainless steel chips 304 and 409, impurities. There are both ferrous and nonferrous materials in the grinding chips. Because 409 is one kind of ferrous material, we can use such magnetic separation to separate it from the other parts. Because 304 is nonferrous material, we cannot use this kind magnetic separation to finish this recycling process “directly”.

The magnetic separator can be used to separate 409 stainless steel chips from the BZZ abrasive grit. The magnetic separator cannot be used to separate 304 stainless steel chips from the BZZ abrasive girt directly. New equipment for magnetizing the 304 stainless steel chips is needed. After the 304 magnetizing process, the 304 can be separated from BZZ abrasive girt by the magnetic separator.

4.1.5 Preliminary Study on New Methods

There are several methodologies for separating ferrous materials and nonferrous materials from the other waste. The 409 is suitable for magnetic separator to separate it from BZZ abrasive grit. Otherwise, because of the non-magnetic particularity of 304 chips, there is no suitable way for separating 304 chips from BZZ abrasive grit. A new separation way is needed for finish the whole recycling process.

An experiment proves that 304 can be magnetized because the chemistry composition of 304 shown in the table below.

Material Properties & Microstructure

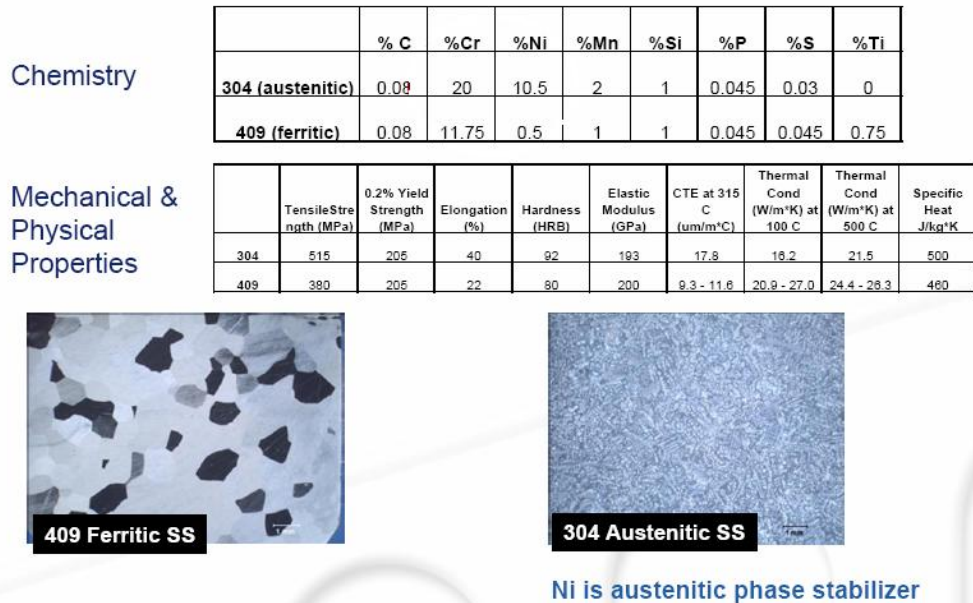


Figure 20 Properties of 304 Steel

The most composition of 304 is austenitic, which is nonmagnetic in room temperature, so the 304 is nonmagnetic. Can the 304 stainless steel chips be magnetized by the magnet or magnetic field? We cannot get any information for this part, so we have designed an experiment for finding out whether the 304 can be magnetized by the magnet or magnetic field in the last weeks.

The experiment is designed as follow:
(1).this is the 304 stainless steel chips



Figure 21 304 Stainless Steel Chips

(2). this is the magnet



Figure 22 Magnet used in experiment

(3).this is the magnet and the chips



Figure 23 304 Chips with Magnet

From the up picture, we can find out that the 304 chips can't be attracted by the magnet because of the non-magnetic particularity of 304.

(4).the is a photo after the magnetizing process



Figure 24 304 Chips after Magnetization

The picture shows that the 304 chips can be attracted by magnet after the magnetizing process. The process of the magnetizing is to put the chips going along with the magnetic field line or the magnet several time. The process can change the direction of molecular magnetic fields, and make them turning towards the same direction.

After proving that 304 stainless steel can be magnetized with the experiment above, we have designed a machine that will automate this process. The machine utilizes a toroid, which is shown below.

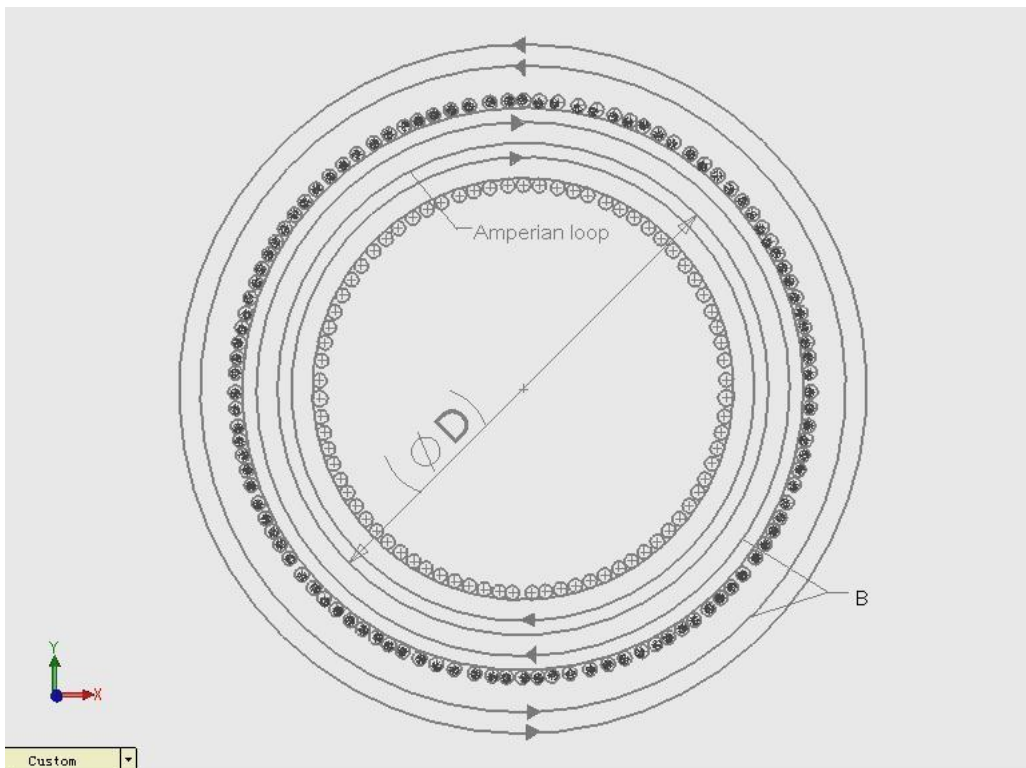


Figure 25 CAD Drawing of Toroid

From this picture, we can find out that the magnetic field of toroid is around it. In addition, the magnetic yields of toroid can be counted out from this formula:

$$(B)(2\pi r) = \mu i N$$

We put the material go along with straight magnetic field is the same as we put the

material go along with round magnetic field.

In order to face the industrial use, we have to design the equipment more suitable for a company to manufacturing or users to utilize. There are several elements, which should be possessed by the equipment.

(1).If the round magnetic field rotates in a high speed and the chips are carried on the conveyer belt in an opposite direction, there is a relative movement between the chips and the magnetic field. Therefore, this equipment can deal with large quantities of chips in a short time.

(2).The effort of the equipment should be notable, and does not change in large range.

The 3-D Model

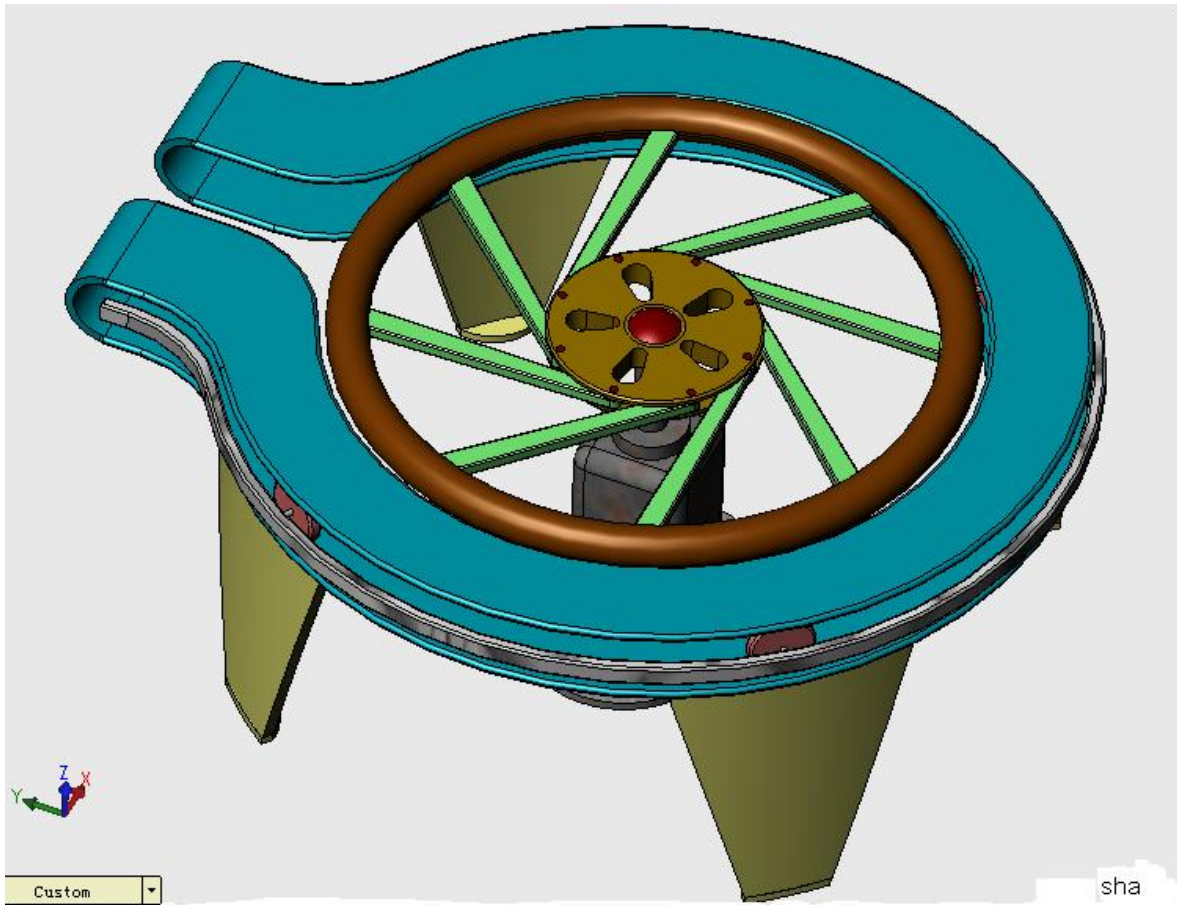


Figure 26 3D CAD Model

- The toroid is in the middle and can rotate in a high speed to make the magnetic field around it rotating in a high speed.
- The conveyer belt is around the toroid, and carries 304 chips on it.
- The motor is in the center of the equipment.

This is another photo of the equipment

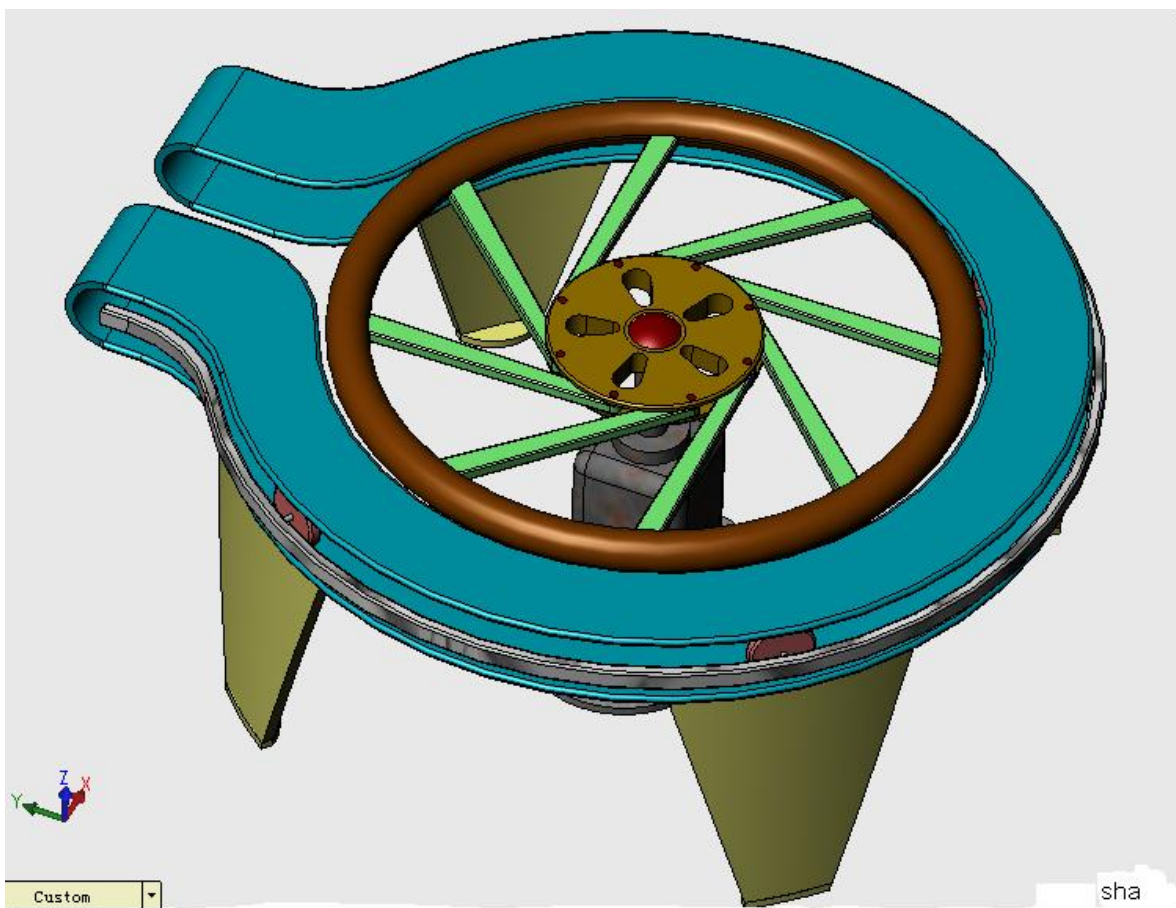


Figure 27 Another view of the 3D Model

The magnetizing process works in the following manner; we put the chips on the belt, and make them going along with the belt around the toroid. On the other side, we make the toroid rotating in a high speed by the motor, so the magnetic field can rotate in a high speed. Therefore, the chips get a high-speed relative movement in this kind of opposite movement.

4.2: Cost Structure

The results are the cost structure for steel making processes, recycling processes, and revenue graph. Table 7 shows the steel making process cost with its materials cost, process cost and market price for grade 304 and 409.

Steel Making Process Cost Structure					
Materials Cost	304 Stainless Steel	409 Stainless Steel	Cost (\$/ton)	cost/ ton 304	409
Chromium	18.00%	10.50%	\$36,000	\$6,480.00	\$3,780.00
Nickle	8.00%	0.50%	\$40,000	\$3,200.00	\$200.00
Manganese	2.00%	1.00%	\$2.45	\$0.05	\$0.02
Nitrogen	0.10%	0.03%	NA		
Carbon	0.08%	0.08%	NA		
Sulfur	0.03%	0.02%	NA		
Silicon	0.75%	1.00%	\$1,020.00	\$7.65	\$10.20
Phosphorous	0.05%	0.04%	NA		
Iron Ore	NA	Balance	\$30		
Titanium	NA	0.0088	\$9,000.00		\$79.20
				\$9,687.70	\$4,069.42
Steel Making Process					
			per unit		
Raw Materials (Scrap)			\$220		
Transportation			\$5		
Melting of Raw Material (Electric Furnace)			\$76.30		
Casting		Hot Roll	\$30		
Total			\$331.30	\$10,019.00	\$4,069.42
Steel Market Price	Hot Rolled Plate	Cold Rolled Coil			
Grade 304	\$4,953	\$4,651			
Grade 409	\$2,000	\$1,800			
* Price are based in Dec. '06, and it still increasing rapidly					

Table 9 Steel Making Process Cost Structure

Alternatively, beside from remaking stainless steel chip into billets, the chip can be selling at a reasonable price to a dealer or dump the chip.

ALTERNATIVE:			
	304 stainless	409 stainless	
Dumping	\$100	\$100	upper estimate
Selling	\$2,700	\$190	

Table 10 Alternative

Table 9 shown the break down of the recycling process, its cost structure and three different options. In each process, there are several methods that can be used to do the job. However, different method produce different outcome. Once this table is complete, best method can be determined through a briefly look at the table.

Recycling Process							
	Option 1	Capacity	Option 2	Capacity	Option 3	Capacity	
1) Chip Collection Machine	Manually	Depend on # of worker	DV-CM Chip Master		Vacuum		
Transportation							
Labor							
Misc. Cost							
2) Separation							
Coolant	Settling Tank	Can handle larg cap.	US Centrifuge CQ3		Pressure Filter		
Ferrous/NonFerrous	Double Drum Magnet		Double Drum Magnet		Double Drum Magnet		
Non-Ferrous	Possible Eddy cur.						
Labor							
Misc. Cost							
Transportation							
2) Packaging Machine	Kurt Chipmunk 2000						
Labor							
Misc. Cost							
Transportation							
4) Remelting Machine	Separate Plant		Blast Furnace		Electric Furnace		
Labor							
Misc. Cost							
5) Casting Machine	Separate Plant						
Labor							
Misc. Cost							
6) Selling							

Table 11 Recycling Process

A revenue equation is generated through analyzing the process cost from

recycling to making and re-selling the chip to consumers. The equation includes all the critical variables, which have a substantial impact to the revenue as well as miscellaneous cost throughout the process.

Revenue = (Amount of Chips * Cost of Chips * Process Efficiency)

- **Collection costs**
- **Separation costs**
- **Packing costs**
- **Melting costs**
- **Casting costs**
- **Selling costs**
- **Buying costs**
- **Overall transportation costs**
- **Miscellaneous**

The result of the revenue equation versus the amount of chips being recycled is shown in figure 8 on the following page, with each different dot line represent different geographical location. The graph on the right shows the revenue over the years at a much simpler level. The intersection between selling and remaking of stainless steel chips revenue range from 1300 to 2400 tons of recycled chips which equivalent to 1.5 to 2.5 years.

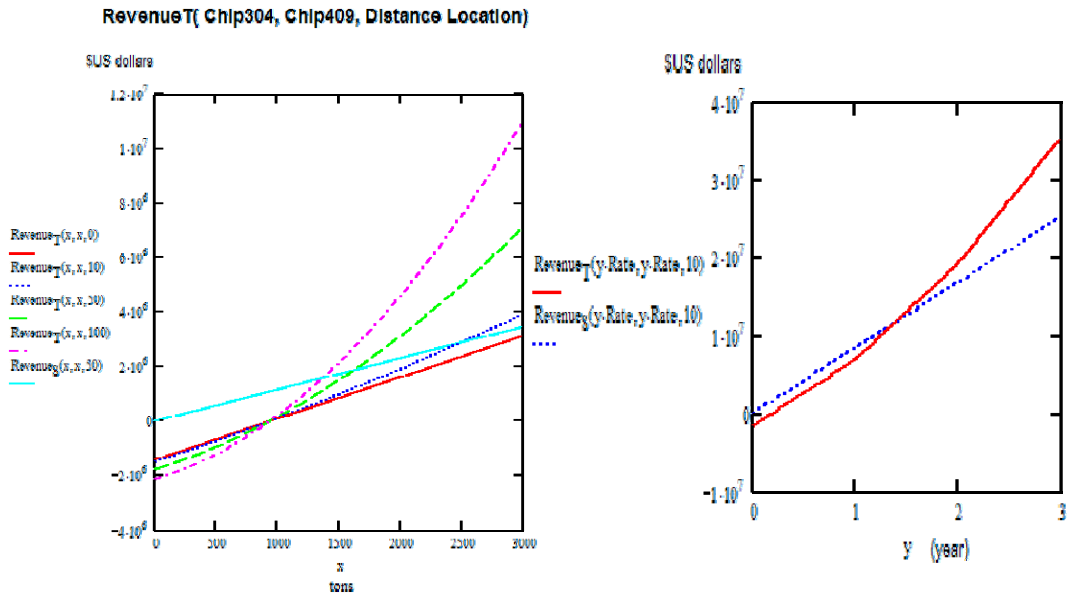


Figure 28 Revenue vs. Tons and Time graphs

5: Conclusions and Recommendations

While we did complete the objectives that we set forth, we believe that in the interest of producing results that are as accurate as possible, further study be performed in certain areas. First and foremost, while we were able to create a cost-structure analysis of the machines and the recycling process, it was difficult to procure the cost of the machines. The reason for this is that companies are reluctant to make this information available to the public, as other companies will see these prices and then be able to compete. The companies will give the price of their machine to a customer who is interested in the machine, but as we were not customers, this information was hard to acquire. Having a more accurate representation of the cost of these machines would allow our cost structure analysis to be more accurate, which in turn, would assist companies further.

It can be seen from the tables and figures in Section 4.2 the cost structure analysis of the recycling process. Companies can use this information to determine whether or not it is economically feasible for them to purchase the machine. It will allow them to have a greater knowledge of the costs involved with owning the particular machine and they can make an educated decision on the potential purchase of a machine. A general machine list along with specifications and applications can be found in Appendix A.

6: Ideas for Future Consideration

Having completed the research portion of this project, there have been several new ideas for separation that have been thought up along the way. While these ideas need more development, perhaps a future group could look into them in order to determine their feasibility. At present, there were no machines found that utilized these principles, and it could be found that these methods are more efficient than other methods. If this is the case, it would most certainly be beneficial to further research these options.

6.1 Flotation Separation

Flotation Separation would be a very basic idea relating to the density differences between the BZZ wheel materials and that of Stainless Steel. We would try to find a liquid denser than the BZZ material at around 3grams per cubic centimeter and less dense than stainless steel at 7.8 grams per cubic centimeter.

Rhenium Trioxychloride is one such liquid. With a density close to 3.867 (Lewis, 2002) it would allow for simple separation of the materials.

The unfortunate drawbacks are that rhenium trioxychloride has a half life and would degrade into less dense matter. I also suspect it would be very expensive to have enough of the liquid to separate tons of material effectively. Then there are the likely health concerns of having a rhenium based chemical, especially in such large amounts.

In all, it's an interesting idea to consider, but just isn't realistic. Even if rhenium trioxychloride were as cheap as water, removing the liquid from the chips and grit would take even more time for the separation phase of recycling.

6.2 Gravimetric Separation

Gravimetric Separation would work quickly, easily, and effectively. The utilization of this method would only require water (or coolant), a pump and a few shelves. It would rely on the different settling rates of the BZZ particles and stainless steel.

The chips would be sent through the liquid medium at some constant pressure. The stainless steel would sink at the fastest rate, and so the lowest shelf should be purely for stainless steel. Similarly, the top shelf would be for the BZZ particles.

Depending on how large the gap is, if a gap exists, in between the two sections then there may be a need for a third shelf area for a section still made up of a combination. This section could then be re-fed into the pump for better purity.

6.3 Flow Separation

Along the same principles of gravimetric separation, flow separation would use the slower settling rate of the BZZ particle as an advantage. The difference is that all of the chips would be in an upward flowing pipe/vat/other liquid container. The rate should be such that the BZZ material is at equilibrium and not moving at all, or moving in the direction of the flow. The flow would also have to be regulated so that the stainless steel still sinks.

Because this method could use coolant as its flow media, it wouldn't be necessary to be concerned over whether the incoming chips are wet or dry. Additionally, the separation would be accomplished first, and then the drying would take place.

6.4 Flocculation Separation

Flocculation is the process of making either the BZZ or the stainless steel stick to themselves so that they form larger particles and can then be filtered more easily. The issues would be with finding a flocculent that has all the desired qualities. Some considerations might be: it causes either the BZZ materials to stick together reliably, or the stainless steel; whether the filtering media would limit the rate at which chips could be separated; would the flocculants be safe (and easy) to work with, and could they be easily removed from the chips afterward.

If flocculation separation is to be a viable consideration in the future, then these considerations must be addressed.

References

advanced-stainless, 2007, <http://www.advanced-stainless.com/productions/Stainless-Steel-Making-Process.htm>

Cruspi, 2007, <http://www.cruspi.com/>

Estainlesssteel, 2007, <http://www.estainlesssteel.com/stainless-steel-news.shtml>

Heywood, Johnson; 1942, Grinding Wheels and Their Uses, Penton Publishing Co., Cleveland, OH

International Stainless Steel Forums. 2007. Introduction to Stainless Steel. Retrieved from: <http://www.worldstainless.org/About+stainless/What+is/Intro/>

Kalpajian, S.; Schmid, S. R.; 2006, Manufacturing Engineering and Technology fifth edition, Pearson Education, Inc., Upper Saddle river, NJ 07458

King, Robert I., Hahn, Robert S.; 1986, Handbook of Modern Grinding Technology, Chapman and Hall, Ltd., New York, NY 10001

Landinst, 2007, http://landinst.com/infrared/application/iron_steel/iron.htm

MEPS, 2007, <http://www.meps.co.uk/Stainless%20Index-asia.htm>

Metalprices, 2007, http://www.metalprices.com/FreeSite/metals/304_scrap/304scrap.asp

MSM, 2007, http://www.msm.cam.ac.uk/phase-trans/2005/Stainless_steels/stainless.html

Murphy, Daniel; Fuchs, Amber; Raposa, Nicholas P.; 2006, The Feasibility of Recycling Grinding Chips, Worcester Polytechnic Institute, Worcester, MA 01609

Shaw, M.C.; 1990, Cutting and Grinding: A Comparison, Society of Manufacturing Engineers, Dearborn, MI 48121

Recycling: It Just Makes Sense. 2007. Retrieve from:

Recycling-guided, 2007, <http://recycling-guided.com/a/336756/Recycling+-+It+Just+Makes+Sense.html>

Steelstrip, 2007, <http://www.steelstrip.co.uk/steel-strip/archives/category/steel-prices/>

Targetblue, 2007,

<http://www.targetblue.com/node1269.asp?url=%2Fnode2045%2Easp%3Fframes%3Dfalse>

http://images.google.com/imgres?imgurl=http://www.makstil.com/images/PROCES-STEEL-MAKING-PLANT_p.gif&imgrefurl=http://www.makstil.com/en/20_proc/20_10_cl/main.htm&h=188&w=250&sz=13&hl=en&start=3&tbnid=kWua7SqQH6E9tM:&tbnh=83&tbnw=111&prev=/images%3Fq%3Dsteel%2Bmaking%2Bprocess%26svnum%3D10%26hl%3Den%26sa%3DN

Lewis, Richard J., Sr.; Copyright ©2002 by John Wiley & Sons, Inc.; Hawley's
Condensed Chemical Dictionary, 14th Edition;

http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=4841545

http://www.google.com/patents?hl=en&lr=&vid=USPAT4312666&id=_C84AAAAEBAJ&oi=fnd&dq=Recycling+nonferrous+oxides+in+iron+and+steel+melting

USGS, 2007,

<http://minerals.usgs.gov/minerals/pubs/commodity/chromium/chrommcs06.pdf>

Worldsteeldynamics, 2007, <http://www.worldsteeldynamics.com/cyclone.html>

worldstainless, 2007,

<http://www.worldstainless.org/About+stainless/How+is+ss+produced/Process+and+production/>

Appendix A – Machine List

This appendix lists several specific machines, which can be used in the chip recycling process. Below each picture is a list of features and specifications. Also listed are the possible applications for each of these machines. A machine name that has a strikeout through the name indicates a previously suggested machine that is not applicable.

Separation

Eddy Current Separation:



Dings Co: Eddy Current Separator
-Not appropriate for stainless steel, too dense.

Applications: dry, metals *less dense than Stainless steel*

Magnetic Drum Separation



Stearns Magnetics/Ohio Magnetics: WPD Wet Magnetic Drum Separators

Applications/Guidelines:

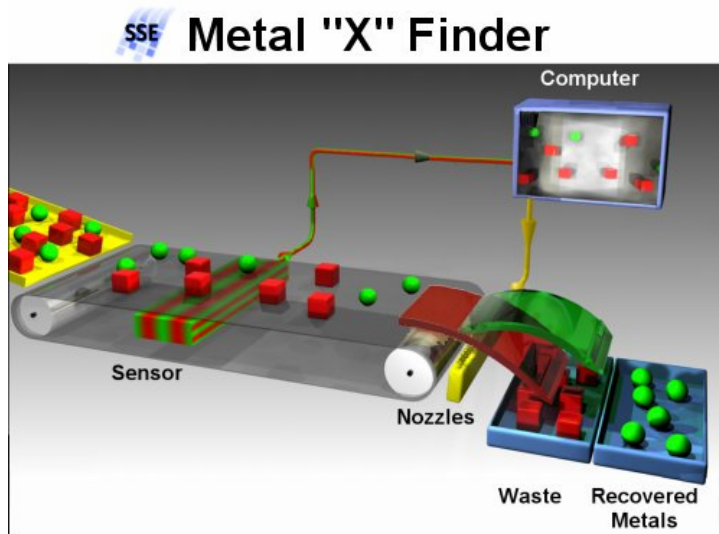
Feed volume should not exceed 75 gpm per foot of magnet width on a 30" diameter, single-drum separator. Similarly, the ratio of magnetic solids to non-magnetic solids should not exceed 15-20 percent for concurrent separators.

Furthermore, single-drum 30" diameter con-current separators should be limited to 3 tph of magnetic discharge per foot of magnet width. Counter-current separators can retain magnetic recovery at a discharge rate 30 percent higher than con-current units.

If feed volumes up to 90 gpm per foot of magnet width must be handled, a double drum separator should be applied. Similarly, if the ratio of magnetic solids to non-magnetic solids exceeds 20 percent, Stearns recommends the use of a double drum separator.

The *double drum WPD separators* (available in double con-current arrangements or con-current primary with counter-current secondary arrangements) can either (1) give a higher magnetic recovery as compared to single drum units or (2) permit higher feed volumes while obtaining the same recovery as single drum separators.

Air Jet Separation

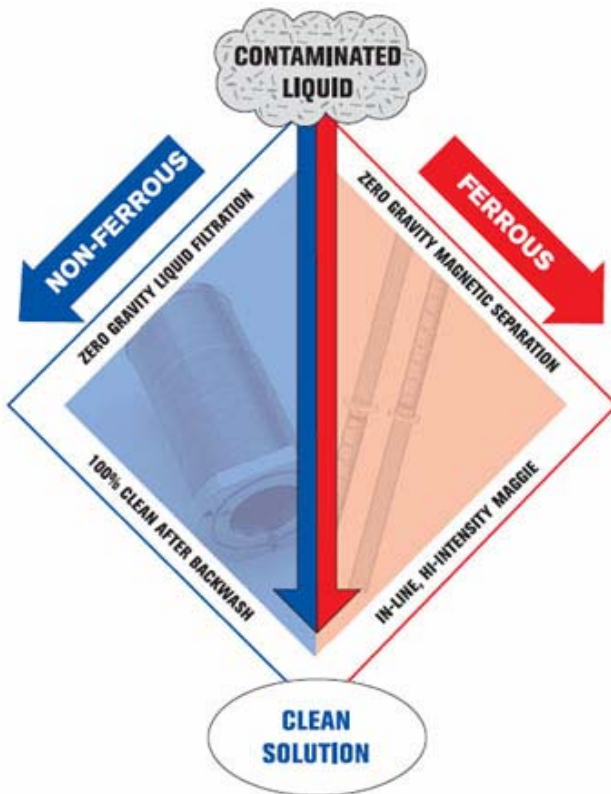


Wendt: Metal-X finder

Guidelines/Principles:

Uses electromagnetic interference to detect metallic objects, then uses a jet of air to push the metallic objects into a separate bin.
Mostly for larger than particulate matter.

Filtration



Zero Gravity Filters: possibly the “Phoenix”
(Needs an estimated flow rate of chips for a proper machine recommendation)

Packaging

Briquetters:

Guidelines/ Principles:

- Can be wet or dry



Prab: PS 1000/1500



National Conveyors: NB 1000



Kurt: Chipmunk 2000



Applied Recovery Systems: RST 1000

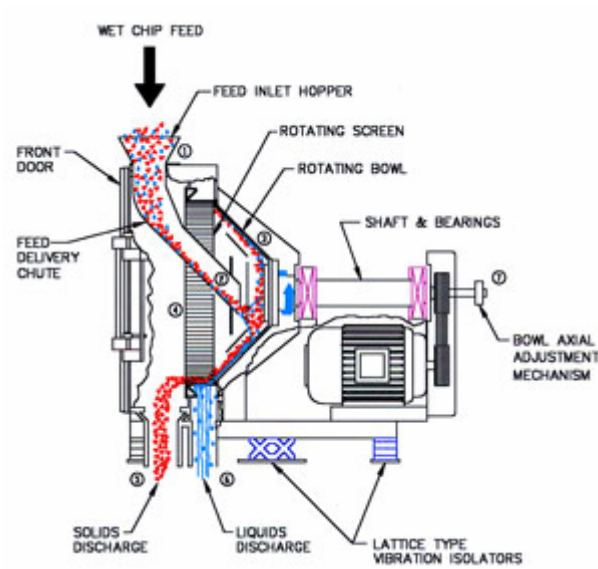
Centrifuges:

(Grinding chips may be too small to work with all of them, company contact is required)

Guidelines/Principles:



US Centrifuge: CQ3



National Conveyers: HD 100 (holes are too large, chips wouldn't be held)



Sanborn Technologies: T 60-2

Typical Applications

- Metal Cutting and Grinding
- Ceramic and Glass Grinding

- Paint Booth Water Curtains
- Waste Oil Clarification
- Zinc and Iron Phosphate Baths
- Vibratory and Tumbling Wastes

Other Machines

Coolant Separator



Abanaki: Chiperator

Guidelines/Principles:

- Requires a slurry (gpm flow rate for proper company recommendation)
- Equipped with float valve to automatically shut off unit when drum is full
- Filters out chips and shavings from plastic, steel, aluminum, ceramic, etc.
- Uses filters that will need to be replaced