The Effect of Machine and Material Parameters on Rare Earth Roller Separation

By

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Submitted to the Department of Mechanical Engineering
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ABSTRACT

This study addresses the affect of machine and material factors on the separation of PET plastic and aluminum on the Rare Earth Roller magnetic separator. The purposes of this study are to gain a better understanding of how separation efficiencies are influenced and develop a performance profile of the Rare Earth Roller to generalize the behavior of other separators used in the recycling industry.

Several operating parameters were explored, including input material concentration, splitter position and feed rate. Experimental design for the tests is presented. Separation performance appears to be dependent on splitter position, a subjective parameter determined by the characteristics of the machine. The separation process was less sensitive to material concentration and feed rate which are specifiable. The results from this study suggest that the Rare Earth Roller can operate at larger volumes of variable concentrations of aluminum and maintain industry standard separation efficiencies.

Thesis supervisor: Timothy Gutowski
Title: The Effect of Machine and Material Parameters on Rare Earth Roller Separation

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CHAPTER

1 Introduction

1.1 Material Recycling

Material recycling processes involve the reuse of recoverable materials from end-of-life products. Such processes can include the reduction of particle size and the separation of materials into two or more output streams. Some recycling systems such as the recovery of PET from plastic beverage bottles can be rather complex, involving several steps to clean, shred and separate the PET from other materials present.

Depending on the process, the input stream can vary considerably by the type and respective concentrations of the materials. In the United States, as well as other industrialized nations, goods recycled include automobiles, paper, electronics, and cans and bottles. The desired output from a recycling process is at least one product that can be treated as virgin material in industry.

Material reduction and separation are governed by operational and input stream factors. The operational factors pertain to the machine and include machine settings, material feed rate, and other parameters controlled by the machine. The input stream factors are the material properties such as size, shape, conductivity, concentration, stickiness, magnetic properties, etc, that affect the performance of the process. Separation technologies are developed to utilize some material properties to better reduce and separate the input stream.

In this study we investigated the performance of a Rare Earth Roller magnetic separator developed by Eriez Magnetics in Erie, Pennsylvania. A Rare Earth Roller is used to separate conductive nonferrous metals from nonconductive materials such as plastics.

1.2 Motivation

In recent years, the recycling industry in the United States has greatly expanded in the volume and diversity of materials processed. The development can be viewed as a response to the unsustainable rate of material consumption by consumers. Much of the waste is disposed of in landfills and a smaller portion is incinerated. To reduce the quantity buried in landfill, federal and state legislation have been implemented to promote the reuse and recycling of materials.

Product recycling can also reduce the use of new resources by displacing the required inputs of manufacturing systems with parts of materials reclaimed from end-of-life products [1]. The substitution of recycled materials for required manufacturing inputs, usually virgin material, constrains the quality of reclaimed materials. Products derived from recycling processes must maintain the same characteristics and purity levels of the required inputs. Technology in this area has developed to uphold such manufacturing standards while allowing recycling facilities to turn a profit.

The understanding of recycling equipment and how performance is affected by common operational and input stream factors are essential to the characterization of recycling processes. This classification can provide insight to the efficiencies of recycling equipment and suggest areas of improvement to increase the quantity and quality of the output. This project focuses specifically on material recycling performance of the Rare Earth Roller magnetic separator by adjusting operational and input stream factors.

1.2.1 Separation Performance

The separation performance is defined as the ability of a process to separate incoming materials into their desired output streams. Equivalent metrics are used widely in the recycling industry to determine the quality of the output material. Lower quality materials are limited in their use in manufacturing processes and are valued as less than virgin material. To produce materials specifically for reuse, recycling facilities focus closely on the separation performance of the processes. This concept will be discussed in more detail in section 2.2.

1.2.2 Plastics Recycling

The end-of-life treatment of plastics is a particularly important area of study. Unlike metals, most plastics have relatively similar physical properties such as density and conductivity. Thus, some plastics cannot be separated by conventional equipment used in the recycling industry but require alternative methods of separation. Unlike paper, different plastics have different chemical compositions and cannot be combined unless homogenous to one type of material.

Once the target plastic is sorted from the input stream, it may be checked again for contaminations. In the case of PET, most of the material is derived from beverage bottles. When the bottles are shredded for size reduction and separation, they can contain traces of aluminum particles from crushed beverage cans. In order to remove the aluminum, the Rare Earth Roller is used which creates two output streams, one of purified PET and the other composed of the contaminant, aluminum. The Rare Earth Roller is an effective instrument in separating nonferrous metals from nonconductive materials. It also plays an important role in handling the increase in flux of plastic recycling in the United States. For these reasons, the Rare Earth Roller was chosen for this study.

Currently the Rare Earth Roller is not widely used in the recycling industry because it typically operates at lower capacity and other more cost effective technologies exist to separate nonferrous metals from plastics. The Rare Earth Roller can be run for smaller batches of material that require further processing for quality enhancement. By investigating the separation performance of this machine at variable operating parameters, we can evaluate how it functions compared to other separation technologies. The results of this study will conclude whether the Rare Earth Roller can run such that it becomes more competitive in the recycling industry.

1.3 Overview of thesis

In this study the separation performance of a Rare Earth Roller was investigated at various machine and material parameters for the purpose of understanding separation processes in the recycling industry. Experiments were designed to test how the concentration of aluminum in the input stream, the splitter angle, and the feed rate of the machine affect the separation efficiencies of the output materials. In the next chapter, we discuss the background of separation technologies, namely the Rare Earth Roller, in recycling. In Chapter 3, the experimental set up is described and in Chapter 4, the results of our experiments are discussed. Finally in Chapter 5, our conclusions are presented.

CHAPTER

2 Background

2.1 Rare Earth Rollers

Rare Earth (RE) Roller magnetic separators were developed to purify nonferrous metals from nonconductive materials. In the minerals industry, RE Rollers effectively reduce hematite from beach sands, feldspar, silica sand, and calcium carbonate. RE Rollers are also used by the food and pharmaceutical industry to remove rust from dehydrated vegetables and granular chemicals [2]. In this study, the RE Roll is evaluated for its separation efficiency in processing PET with traces of aluminum particles.

The RE Roller utilizes an eddy current effect to separate the nonferrous metals from the plastic particles. The permanent magnets on the roller at one end of the feeder belt create a magnetic field around the roller. When the conductive materials pass through the field, an electrostatic charge is induced and the materials experience a resulting force from the applied field [3]. This interaction is known as the eddy current force. When the charged particles pass through the field, they are pulled toward the permanent magnet until gravity overcomes the attraction. These particles will drop down and collect in one area whereas the plastic particles will follow their normal, uninhibited trajectory off the belt into another area [4]. Figure 2-1 diagrams the path that the materials would ideally follow as a result of the eddy current force where the right stream represents the plastic.

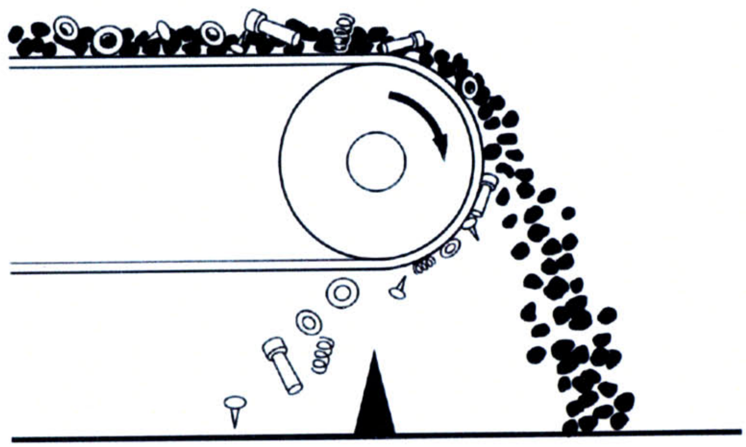

Figure 2-1 Trajectory of output streams due to the eddy current force

2.2 Separation Metric

The Bayesian Material Separation Model was constructed to provide a simple characterization for the separation efficiencies of a recycling process. This model assumes there are two output streams – one of target material and the other of non-target material [5, 6]. The ability of the process to separate the target material into the target output stream from the input stream is expressed as a ratio, *r*, and the ability to separate the non-target material into the non-target output stream is expressed as ratio, *q*. Figures 2-2 and 2-3 depict the separation process of target and non-target materials respectively.

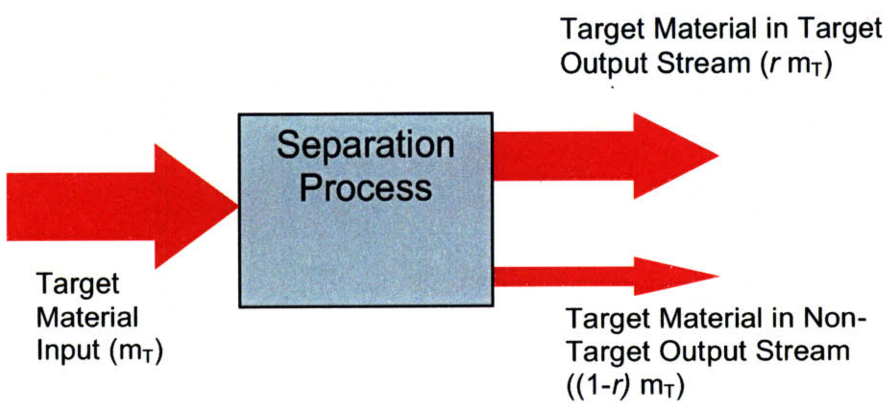

Figure 2-2 Separation of target material

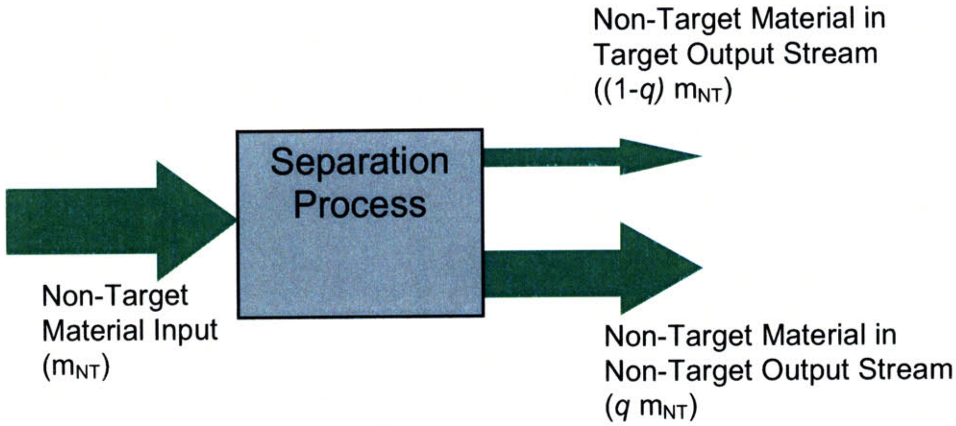

Figure 2-3 Separation of non-target material

Many studies have been conducted to investigate the separation performance of other equipment used in the recycling industry. Most literature about separation processes describes the performance of a process under a single set of conditions. Figure 2-4 plots the performance of many separation processes in terms of r and q [7-13]. The results, however, are typically presented using only one operating point. Limited research has been done to map these processes under multiple operating and input stream parameters.

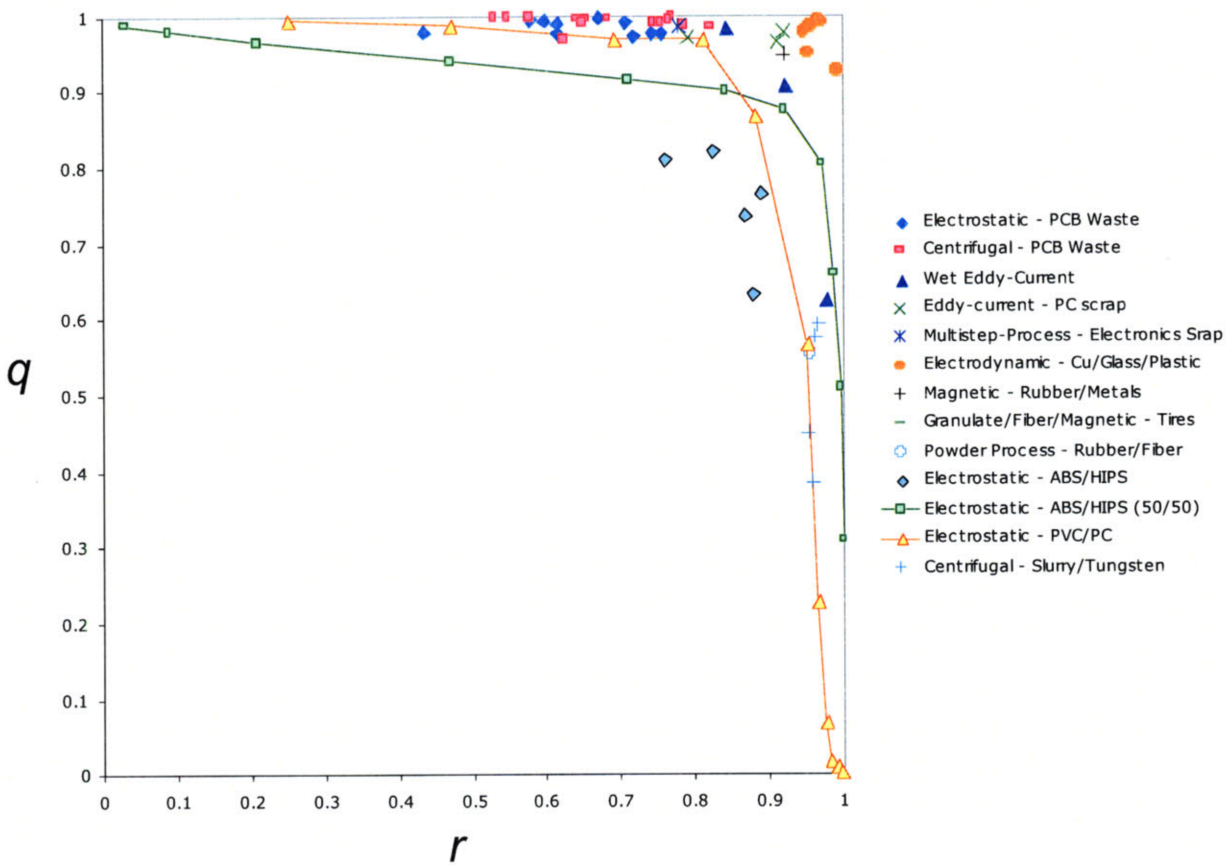

Figure 2-4 Separation efficiencies for various processes expressed in *r* and *q*

2.3 Theoretical Model

2.3.1 Normal Curve Distribution

The separation process is characterized largely by input material properties. The properties of the materials can vary, generating a distribution of responses to the separation mechanism. When the process physically divides the input stream into two or more output streams, the distribution can be separate or overlapping. In some cases the separation process employs physical mechanisms to divert target or non-target particles into a different area. For separate distributions the process can ideally partition the input stream into respective output streams. However for overlapping distributions, separation efficiencies are reduced because a division point must be chosen in this overlap region to optimize the one or all the output streams [14].

2.3.2 Proximity Effect Model

According to experimental results of the RE Roller and other separation equipment, particle interaction can greatly affect the quality of the output streams. In the case of PET and aluminum separation, particles can stick together and knock each other off their trajectories. The proximity effect model was developed to describe how separation efficiencies can be influenced by the concentration of target and non-target materials assuming that particle interaction occurs more frequently at high concentrations [14].

This model assumes that the target separation efficiency, r, is 1. The number of particles of non-target material carried over per particle of target material is N, where N varies based on material concentrations. Assuming that c is the concentration the target material in the input stream, the faction of target particles affected is cN. It follows that the faction of non-target particles affected is $cN(1-c)$. Figure 4 diagrams the material flow for the non-target material and how the output stream is affected by particle interaction. The resulting non-target separation efficiency, q, becomes $(1-cN)$ which gives a linear relationship between concentration and efficiency.

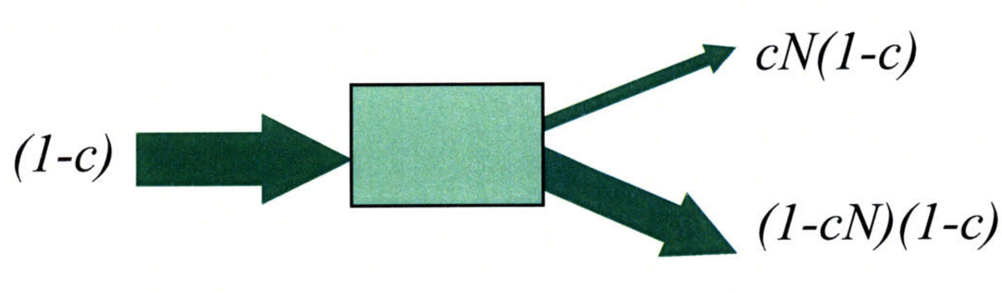

Figure 2-5 Separation of non-target material by the proximity effect model

CHAPTER

3 Experimental Method

3.1 Apparatus

The machinery used in this study was the Single Rare Earth Roller magnetic separator designed and manufactured by Eriez Magentics. The permanent magnet in this device was constructed with ERIUM 3000 permanent magnetic discs alternating with thin steel pole pieces along a shaft. This apparatus can produce a magnetic field exceeding 21,000 gauss. The magnetic roll is used as the head pulley and connected to a self cleaning tail pulley by a thin Teflon coated belt. The belt conveys the feed material into the magnetic field. The nonferrous metals are attracted to the roll while the nonconductive materials follow a normal trajectory off the belt. An adjustable splitter device is used to separate the two streams. A vibratory feeder with a mounted hopper is used to release materials onto the belt [2.1]. Figure 3-1 illustrates the components of the RE Roller from a slide view and actual photo of the apparatus. Figure 3-2 is a photo of the control panel for the adjustment of feed rate and belt speed.

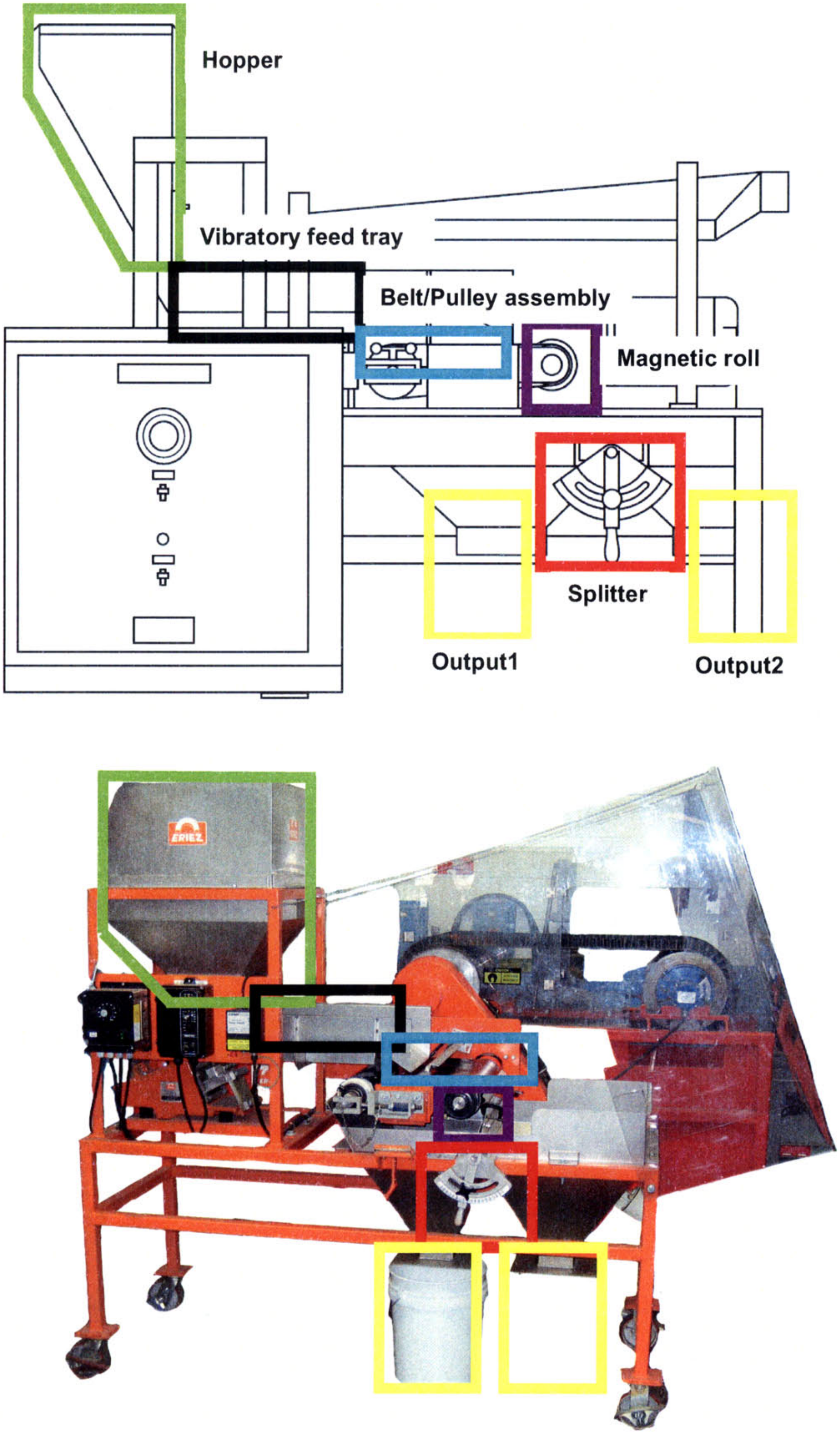

Figure 3-1 Components of the Rare Earth Roller

Figure 3-2 Control panel to adjust feed rate (left) and vibratory feeder frequency (right)

3.2 Material Characterization

Various technologies exist for the treatment of many different materials in the recycling industry. Materials are characterized by their physical properties and can be separated out of the stream by the property which differentiates them from other materials. Some processes categorize the material by its shape, size, conductivity, density, surface charge capacity or a combination of these and other factors.

The materials used in the experiments presented in this study were pieces of PET from beverage bottles and aluminum from beverage cans from a 3/8 shred. A 3/8 shred reduces the particle size to at most 3/8 inch in size. The largest particles in the sample measured upwards of 1 inch (2.54 cm) and the smallest particles were dust like in appearance. The sample was sent to Eriez Magnetics by a recycling facility for testing and kept as potential testing material. Figure 3-3 shows the typical size of the materials used in this study.

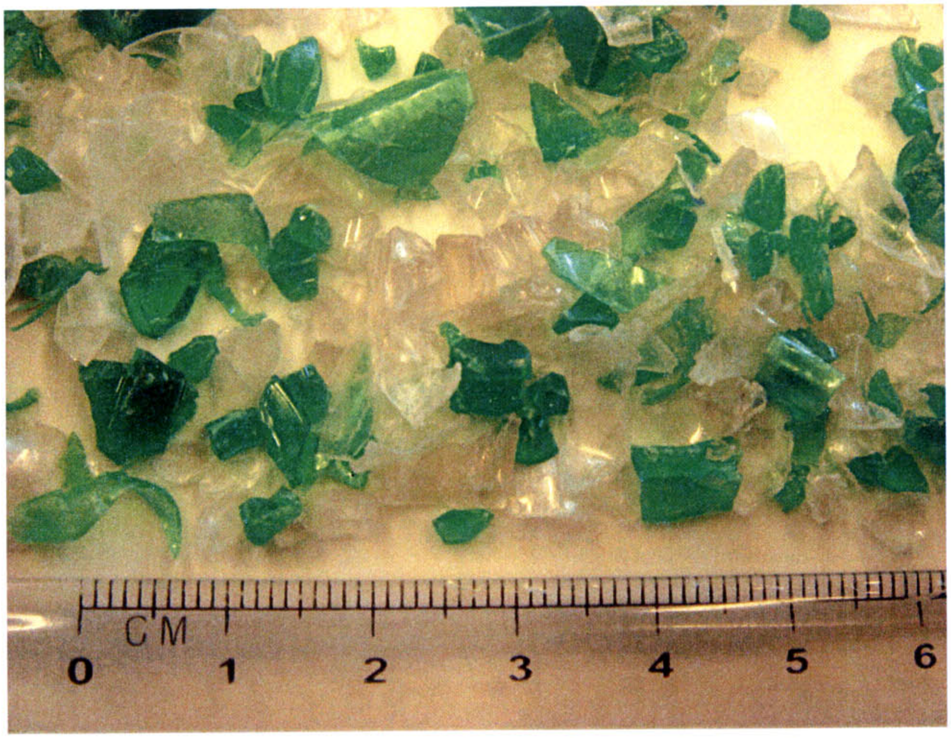

Figure 3-3 Input materials with scale

3.2.1 Material Contamination

Recyclers must be aware of possible contamination in input stream materials. Contamination can be introduced at earlier steps in the recycling process through many mechanisms, including inappropriate products with incompatible materials being added to the initial input stream, additives used during various cleaning and size reduction steps, and improper sorting in upstream processes. Common contaminations include unwanted materials from other streams, dust from the surroundings, and chemicals from the cleaning processes. In our experimental runs, we encountered several contaminants that would diminish the separation performance. Along with aluminum, crushed penny pieces were found in the output container. There were also traces of ferrous dust which clung onto the magnet. These dust particles did not move with the belt but remained attracted to the roll. Contaminations such as ferrous dust wear out the belt at exceptional rates and could potentially damage the machine. Along with the plastic, wood particles and beverage bottle labels were found in the output stream.

3.3 Experimental Plan

To understand the separation performance of the Rare Earth Roller magnetic separator, three sets of experimentation were designed and carried out at the Eriez Magnetics facility in Pennsylvania. The experiments varied the concentration of aluminum in the input stream, the splitter position and the feed rate. Samples were taken to determine the separation efficiency of the target and non-target output.

3.3.1 Mixture Preparation

The concentration of aluminum was initially unknown in the sample set out for testing. To prepare input material of specific concentrations, the sample was run through the RE Roller three times. Each time the output materials were collected, which are referred to as heads (target material aluminum) and tails (non-target material PET), they were separately loaded into the RE Roller and processed again. The tails portion was processed twice where each time the remaining aluminum from the run was collected in a separate bucket. The heads portion was also processed twice where the small amount of plastic that filtered out was discarded because it contained many pieces of aluminum. After the three runs, we had a bucket of mostly aluminum and one of mostly plastic. These materials were then considered to be pure or stock aluminum and plastic for the purposes of remixing.

All the experiments conducted used a 5mil belt.

3.3.2 Experimentation Based on Concentration Variation

Some literature indicates that separation efficiencies strongly correlate to the amount of target material in the input stream [15]. A series of experiments were conducted to better understand the effect of concentration of the input materials on separation performance of the RE Roller.

Two sets of tests were run on the RE Roller varying the percentage of aluminum in the input mixture. The belt speed was kept around 140 ft/min for both tests. The first tests aimed to examine how lower concentrations of aluminum could affect the separation performance. Portions from the stock PET and aluminum were combined to create an input stream of 0.0819% aluminum. Samples were taken from the heads and tails in such a way as to accurately represent the amount of aluminum and PET in the output streams. One method was to cup half the heads portion and package it as a sample. The tails portion contained such small amounts of aluminum that samples were taken by hand without the concern of misrepresenting the tails contents. Due to the lack of materials, the plastic is reused in the following runs with changes to the concentration of aluminum. To increase the concentration of aluminum in subsequent runs, more aluminum stock was added. We aimed to continuously add 0.02% to each run until the 9th run in which the concentration was increased by 0.03% and the 12th run in which it was increased by 0.04%. To account for the aluminum that was removed as samples from the output streams, we hand sorted a small quantity from the heads and tails of each run to determine the percentage of aluminum present. From these values, we calculated the amount to add in make up for the lost aluminum and to increase the concentration for the next run. The material was well mixed each time aluminum was added by hand or a pouring technique which involved dividing the material into two buckets and then simultaneously pouring it back into one container.

The second set of tests sought to investigate the separation performance at higher input levels of aluminum. Using stock aluminum and PET, a mixture of containing 17% aluminum was produced. Higher concentration values could not be reached due to the limitation of materials. The concentration was reduced by 3% until 8% was reached, then by 2% until 2%, then by 1% and 0.5%. In this series of runs, roughly 50g samples were taken from the heads and tails portion. However, instead of calculating the concentration of aluminum in these samples, we assume that the heads will roughly be completely aluminum and the tails plastic. In the following runs, stock material is added to reduce the concentration of aluminum. The same mixing techniques are employed in these runs.

The RE Roll is not commonly used to process PET and aluminum obtained from crushed bottles and cans because there are other more cost effective technologies that can handle greater volumes. This tool could become a more flexible option if the separation performance is shown to be consistent across varying levels of aluminum. If the separation performance is found to degrade at certain concentrations, we can better use this information to profile the RE Roller and other similar magnetic separators.

From literature review and the results from the initial separation to produce pure materials for remixing, the RE Roller is expected to perform better at lower concentrations of aluminum [16].

3.3.3 Experimentation Based on Splitter Angle Variation

Aluminum particles are attracted to the magnetic roll by an eddy current force and fall off the belt into a different compartment. However, a few aluminum pieces follow the trajectory of plastic pieces as trajectory is affected by particle orientation and shape especially if the pieces are folded. When the splitter is raised, these aluminum pieces will not end up with the plastic as they are too heavy and will be blocked by the splitter.

The position of the splitter tool can affect the separation efficiencies to a great extent. Due to particle interactions and the non-uniform size and shape of the input stream, the aluminum and plastic pieces do not always behave has they should. Some aluminum particles are less affected by the eddy current force and follow a similar trajectory as the plastic. In this case the splitter can be raised to catch the aluminum pieces as they tend to fall closer to the magnetic roll. By raising the splitter, plastic particles will also be caught and sorted with the target materials.

Experiments varying the splitter angle were conducted to determine the separation efficiencies of the output. The input concentration was approximately 12% aluminum and the belt speed was kept at 140 ft/min. The RE Roller was let run for about 10 seconds until the materials uniformly coated the feeder tray. The output collected was set aside. The splitter angle was adjusted for each run from 32 to 36.5 degrees in increments of 0.5 degrees. The runs lasted 5 seconds and all the output material was collected as samples. Figure 3-4 illustrates the position of the splitter and Figure 3-5 shows the dial used to change the splitter angle.

Figure 3-4 Splitter device in operation

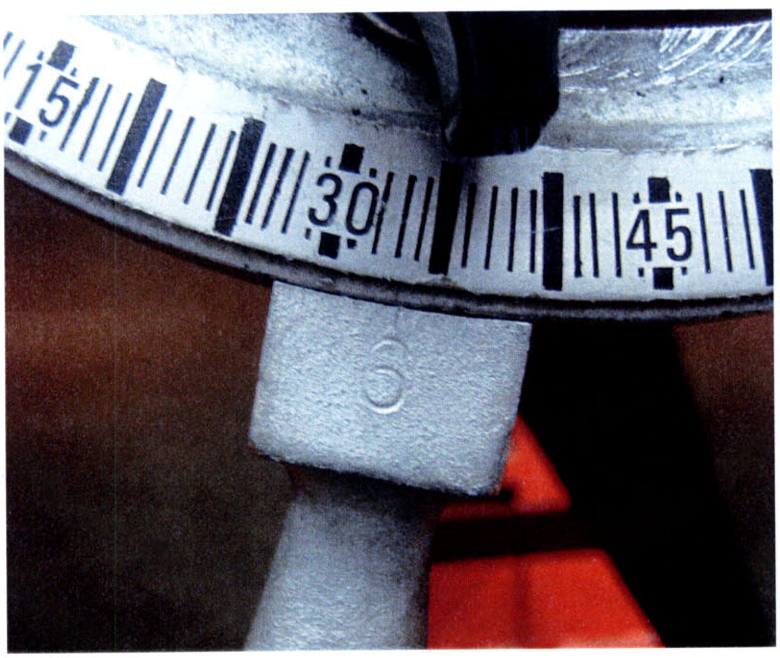

Figure 3-5 Dial to measure and adjust the splitter angle

The purpose of this experiment is to characterize how the change of machine parameters, such as the splitter angle, can affect separation performance. With this information, we can better analyze RE Roller performance.

From observation, the splitter position affects the separation efficiencies considerably. When transferring the heads and tails of each run into sample bags, the change in the amount of aluminum in the heads and tails was noticeable. When the splitter angle is increased, the device shifts closer to the belt and consequently, the target material efficiency, r, improves. At lower splitter angles, it seems the non-target efficiency, q, will trump because less aluminum particles pass over the divide.

3.3.4 Experimentation Based on Feed Rate Variation

Experiments designed to evaluate the separation performance of the RE Roller by feed rate variation were also conducted. In this series of tests, the belt speed was operated at 132 ft/min. The feed rate as defined in this context is how quickly the material is processed which is measured in pounds per hour. The feed rate is crucial for a machine's competitiveness in industry processing. As the RE Roller is known to be a low volume device, experiments were executed to understand how separation efficiencies are affected at relatively high and low feed rates.

Specific feed rates were obtained by a trial and error method. The vibratory feeder was turned up to 45 Amps to reach a feed rate of around 1400 lb/hr. An input stream of a constant aluminum concentration was used and run for 30 seconds when the material uniformly coated the feeder tray. The heads and tails were then weighed to determine the quantity processed per unit of time. At 45 Amps, the feed rate correlated to 1383.2 lb/hr and a sample of 10 g from the heads and 50 g from the tails were taken. This process was continued until a feed rate of 1200 lb/hr was reached. The feed rate ranged from approximately 1400 to 600 lb/hr at 200 lb/hr intervals, 600 to 200 lb/hr at 100 lb/hr intervals, and finally at 150 lb/hr. Due to limited quantity of input materials, the heads and tails from each run were recombined for reuse after samples had been taken from them. The material was mixed by hand or a pouring technique in involved dividing the material into two buckets and then simultaneously pouring it back into one container. In order to maintain the concentration of the initial input materials, enough plastic was discarded from the tails to offset the 10 g sample taken from the heads after each run.

Because the RE Roll is not used as a high volume processor, we speculate that separation performance diminishes with an increased feed rate. However, if a lower separation efficiency is acceptable for the output material, the RE Roll can operate at higher volumes. The feed rate can also be increased if the input materials were processed more than once or on a double RE Roller. A double RE Roller is constructed with two magnetic rolls positioned so that the target or non-target material separated by the first roll supplies the vibratory feeder for the second roll. Further experimentation must be done to determine how separation efficiency is influenced by multiple runs and whether an increased feed rate for a multiple step process is financially viable in the recycling industry.

3.4 Sample Analysis

In each set of experiments, samples from the heads and tails were collected in different steps and quantities. However, the collection method was similar to ensure the samples collected were unbiased and accurately represented the ratio of PET to aluminum. The heads portion was mixed slightly before samples were scooped out by an instrument or by hand. The tails often contained an overwhelming amount of PET compared to aluminum and samples were usually not mixed and taken by hand.

The samples were then analyzed to determine the separation efficiencies, r and q, for the process. The PET and aluminum from the samples were sorted by hand to determine their weight concentration. This ratio was used to then estimate the actual amount of PET and aluminum present in the heads and tails. This calculation was done again for samples with contaminations, specifically penny pieces, to ensure a more accurate weight concentration. The penny pieces were simply removed and the separation efficiency was determined.

CHAPTER

4 Results and Discussion

4.1 Performance from Concentration Variation

The separation efficiencies were determined for the outputs and plotted against each other. The results are shown in Figures 4-1, 2 where Figure 4-2 represents the efficiencies after the penny contaminations were removed. The different points on the graphs represent the process being operated at various concentration points. In the case of magnetic separation of PET and aluminum, the concentration of aluminum varies from 0.08 – 1.09% in the low concentration data series and from 0.5 – 17% for high concentration.

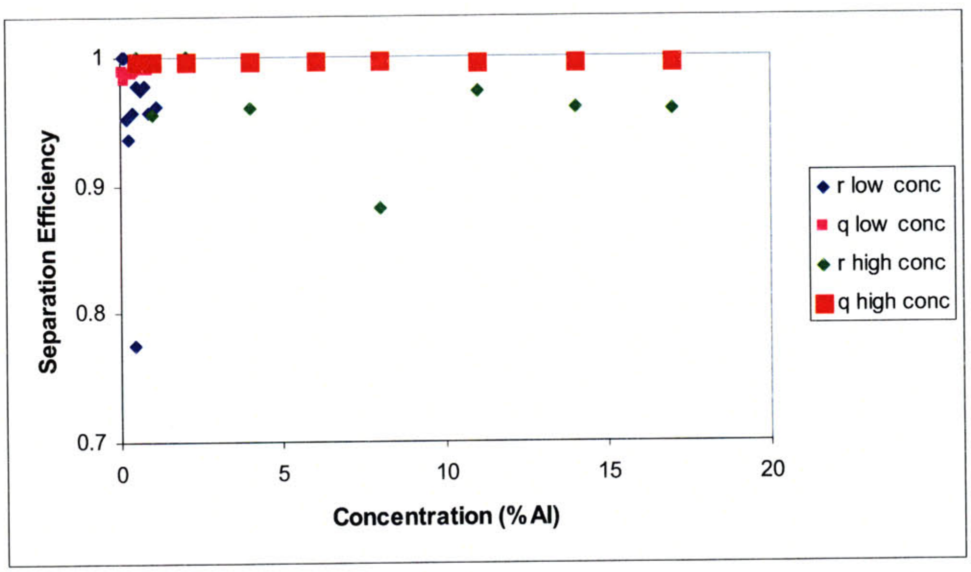

Figure 4-1 Target and non-target separation efficiencies with contaminations

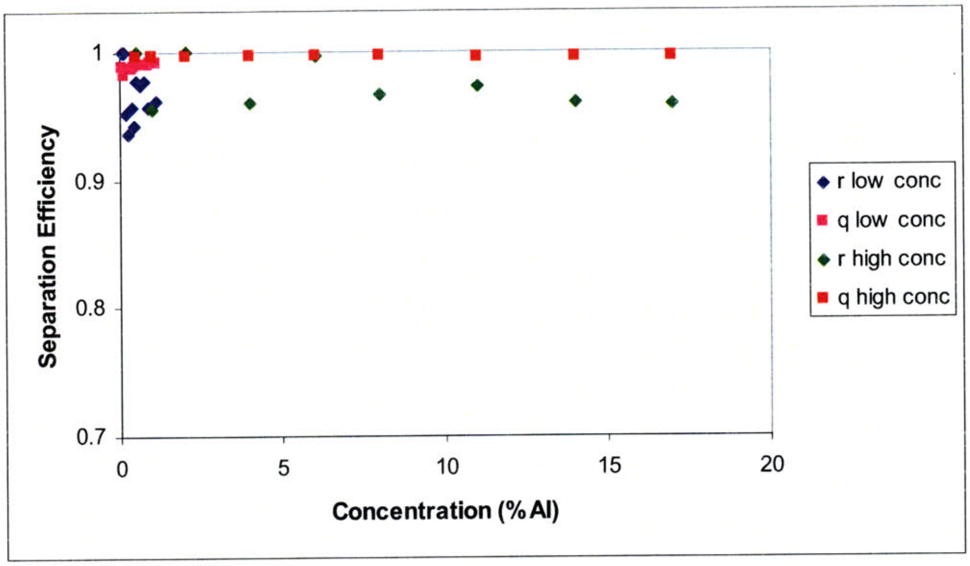

Figure 4-2 Target and non-target separation efficiencies without contaminations

The findings will be analyzed using the data after the penny pieces were removed. Contaminations were discounted because the input materials were assumed to contain only PET and aluminum from our experimental design. Figures 4-3, 4 show that for both sets of experiments, the process is relatively concentration independent. At lower concentrations, the non-target separation efficiency, *q*, is near 1 without large deviations across different operating points. The target separation efficiency, *r*, ranged from 0.936 to 0.978 and the spread was also larger. At higher concentrations, *q* becomes close to 1 and the deviation is trivial. This is due to the lack of aluminum in the non-target portion. The spread in *r* cannot be discounted as values range from 0.957 to 0.998.

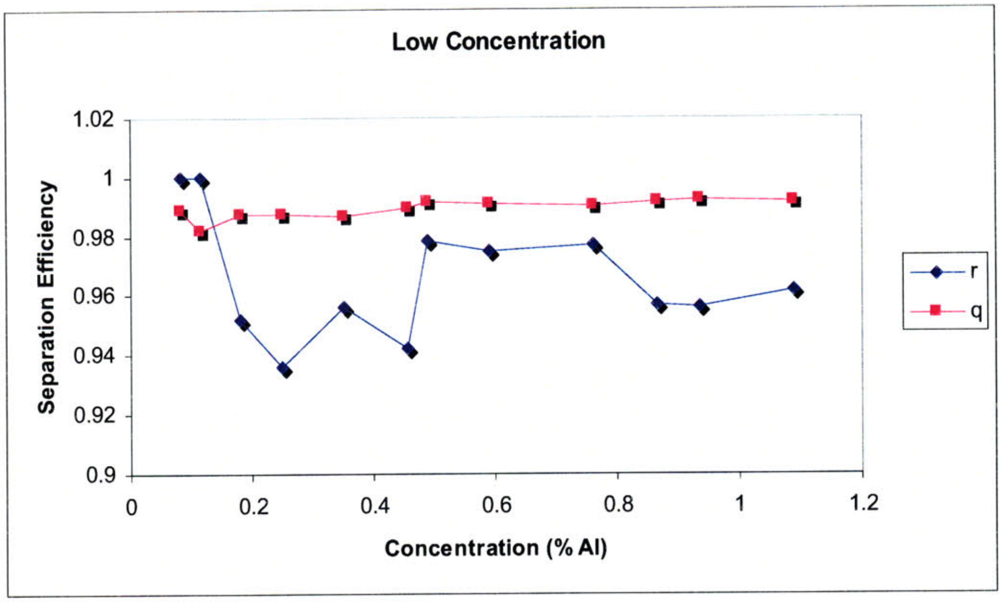

Figure 4-3 Target and non-target separation efficiencies at low concentration

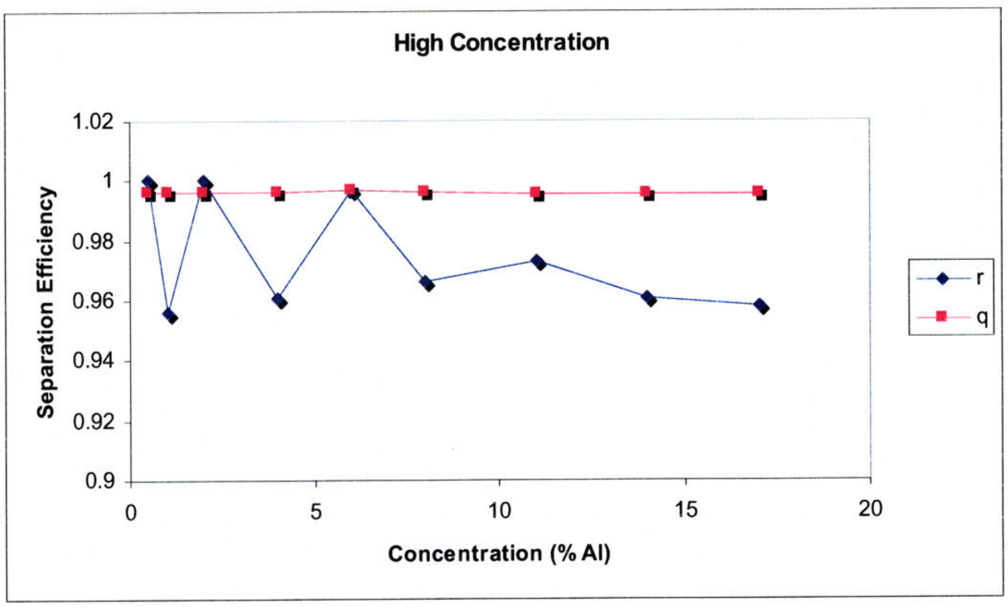

Figure 4-4 Target and non-target separation efficiencies at high concentration

The two series of experiments were conducted at different times but run at similar machine settings. To determine whether the same results would be obtained in repeated runs, the high concentration input was eventually reduced to 1% and 0.5% so that the material parameters would overlap with the low concentration input specifications. The results confirm that the separation performance at the overlap points does coincide.

According to the results, separation efficiencies are relatively concentration independent. This conclusion is unexpected because we have assumed that machinery performs better at less demanding parameters. However, the RE Roller is not fully understood in this regard. The behavior of the process beyond a 17% concentration is unknown and we can only speculate about the input parameters that correspond to maximum efficiencies. The average input aluminum concentration in industry is typically less than 1%. This implies that the RE Roller is capable of handling industrial grade input materials and yielding high separation efficiencies.

The experiments were subject to other changes in addition to machine and material input parameters. Potential errors in the results can be traced upstream to the shredding of the beverage bottles and cans. While shredders are specified to a 3/8 shred, recycling facilities do not operate under the same conditions or run the same model of shredder. From observation, the materials were largely spread apart when they reached the belt and therefore, particle interference is discounted as a major source of error.

There are two types of machine parameters that can be changed on the RE Roller – specifiable and subjective. Specifiable parameters include the material feed rate and the belt speed, whereas the subjective constraints consist of the splitter angle. This parameter is subjective because the splitter is a device that varies on each machine. The splitter is simply comprised of a piece of sheet metal bent at an angle. Although a scale is attached to specify the splitter angle, the device likely depends on the machine. The RE Roll was used and moved to another location in the Eriez Magnetics facility between the low and high concentration experiments. Changes in such subjective settings may also be another source of error.

4.2 Performance from Splitter Angle Variation

The separation efficiencies for varying the splitter angle were analyzed and the results are shown in Figures 4-5 and 4-6. In Figure 4-5 the efficiencies are plotted again each other and the data points represent the process being run at different splitter angles. Figure 4-6 presents the information differently to visually discern how the efficiencies are affected by increasing the splitter angle. The angles tested ranged from 32 – 36.5 degrees

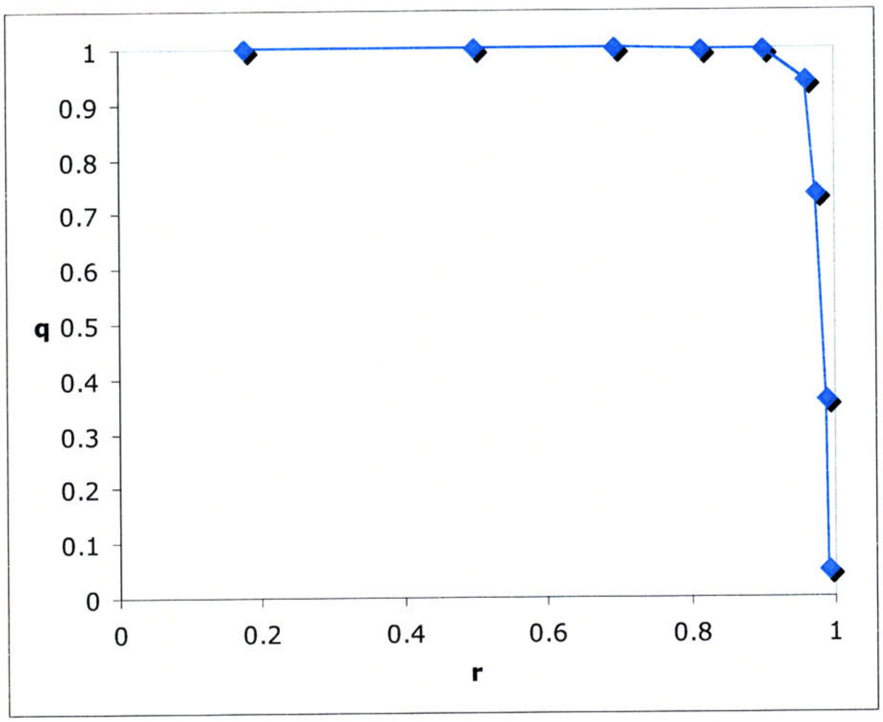

Figure 4-5 Target and non-target efficiencies plotted against each other

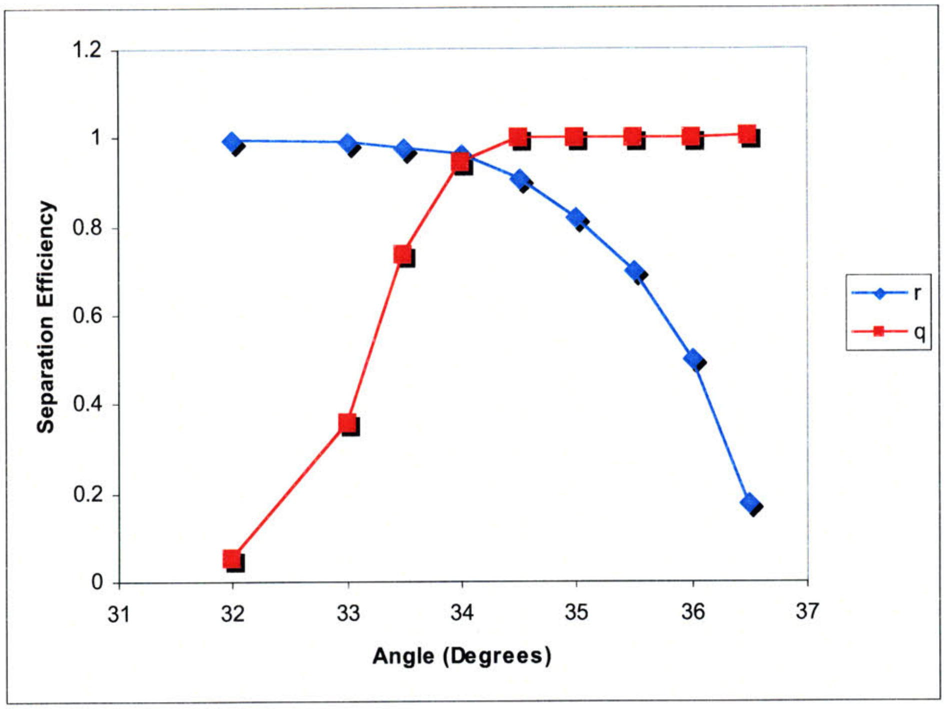

Figure 4-6 Separation efficiencies based on splitter position

Penny pieces were not found in this set of samples so the data was not mended. From both figures, it is shown that the separation process is very sensitive to splitter position. At the lower bound of 32 degrees, much of the aluminum found its way into the non-target material output which resulted in a q of 0.05. As the splitter angle was adjusted, q began to improve. Subsequently as q improved, r began to worsen although at a much slower rate until the two efficiencies reached the same value. The reason r declined much slower is because aluminum has a substantially higher density than PET. While PET collected in the target output as splitter angle increased, the weight ratio between the aluminum and PET did not change significantly. The efficiency r degrades rapidly past an angle of 34 degrees while q stabilizes at an efficiency of almost 1.

The results of this experiment met the expectations developed during the sample collection process. Visually, we were able to discern that at lower splitter angles the aluminum particles that were not as attracted to the magnetic roll bypassed the splitter. At higher splitter angles, the splitter blocked almost all the particles which were slightly attracted to the roll. Thus high efficiencies r is observed at 32 degrees and q at 36.5 degrees.

Similar to the errors suspected in tests with varying concentrations, the potential errors in this experiment can be traced to the processing of material, namely the shredding of the beverage bottles and cans. Shredders and other recycling tools are operated differently by facilities. There are limitations to the scope of this study because we cannot assert how materials from other recycling facilities behave.

The results of these experiments imply that the separation performance can be greatly affected by the change in subjective machines parameters such as splitter angle. The data collected will provide a better understanding of magnetic separation processes and a detailed profile of the RE Roller in particular.

4.3 Performance from Feed Rate Variation

The last set of experimentation was conducted varying the feed rate of the separation process. The separation efficiencies were determined and plotted against each other in Figure 4-7. The different points on the graph represent the process performance at different feed rates shown in Figure 4-8. The feed rates sampled ranged from 148.5 – 1383.2 lbs/hr.

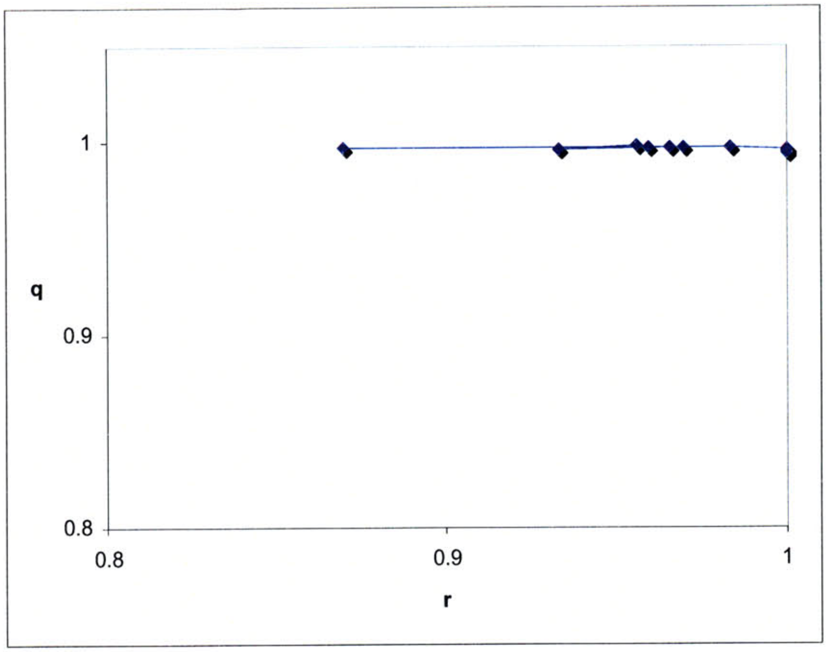

Figure 4-7 Target and non-target efficiencies plotted against each other

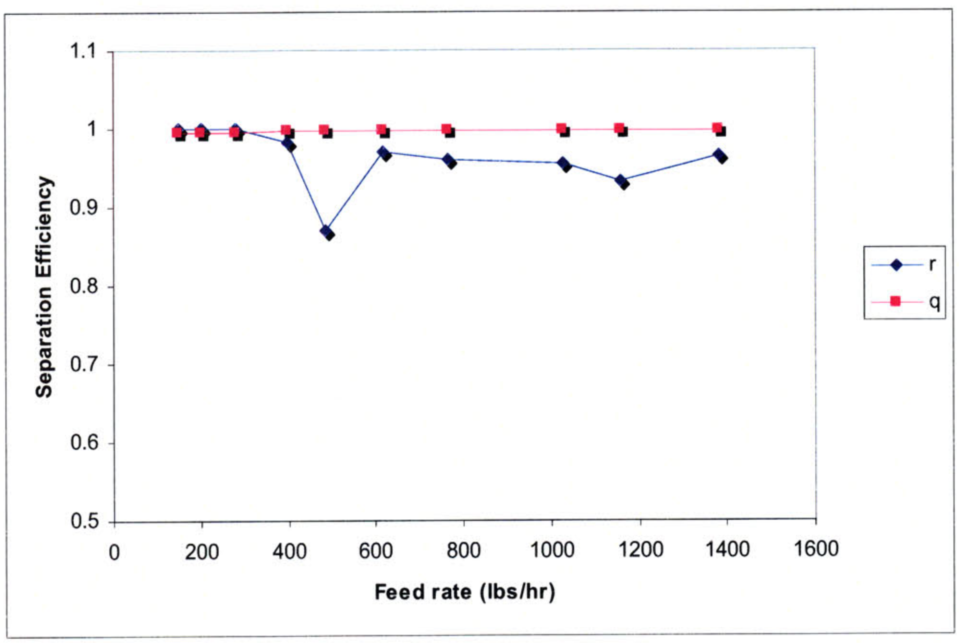

Figure 4-8 Separation efficiencies based on feed rate

According to the results, q is feed rate independent over the ranges investigated in the study. At 148.5 and 1383.2 lbs/hr the value of q is 0.995 and 0.997 respectively, and efficiencies at all other operating rates fall into this range. The deviation of q across operating points is also negligible. Target separation efficiency, r, is slightly more affected by the change in feed rate. As feed rate increases, *r* declines to some extent specifically from 1 to 0.93, and the spread of results is more considerable.

The results of this study disprove the assumption that RE Roller separation performance degrades substantially as feed rate increases. The implications of these findings would allow the RE Roller to become more competitive in the recycling industry. PET and aluminum from bottles and cans are currently processed at over 1000 lbs/hr by various other technologies. If RE Rollers can maintain industry standard performance at relatively high volumes, they can become more financially viable options.

As mentioned previously, errors within the test may be rooted in how the initial input materials were processed. The variation of material properties which includes size, shape, conductivity, etc. was not taken into account in the analysis of the output streams. Due to the limited amount of input material, another bucket of shredded PET and plastic provided by a different recycling facility was used along with the original material. There was no noticeable difference between the two containers yet it is unclear how the two facilities processed the materials. From photos taken of the process, it appears that particles were relatively spread out on the belt even at high feed rates. Thus, particle interaction was discounted as possible error in our analysis.

In addition to the vibratory feeder frequency, the gate at the bottom of the hopper was also adjusted to obtain specified feed rates by a trial and error method. As there is no indicator of gate width unless measured when the hopped is empty, the dimensions of the opening were not recorded. The gate was adjusted which resulted in a thicker layer of material flowing onto the feeder tray. The varying thickness of material on the tray from the change in gate width, a subjective operating parameter, may be cause for error in the results.

CHAPTER

5 Conclusions and future work

5.1 Summary

This study has presented an experimental investigation of the affects of operating and material parameters, namely the concentration of input material, feed rate and splitter angle position, on the separation efficiencies of a Rare Earth Roller. The aim was to better understand how magnetic separators like the RE Roller process material in the recycling industry. The results have demonstrated the separation process is more independent to aluminum concentration and feed rate than to splitter angle. With this data, we can provide a recommendation on the parameters which allow the RE Roller to operate most efficiently within the scope of this study.

5.2 Conclusion

Several remarks can be made regarding the separation efficiency of the Rare Earth Roller at the parameters examined. Contrary to expectations, target and non-target efficiencies were largely unaffected by the change of aluminum concentration in the input material. Two separate trials were run leading to the same result. At concentrations below 1% which is roughly the industry average, efficiencies were high which is favorable to the use of the RE Roller in recycling facilities.

The process was highly dependent on the splitter angle of the machine. At lower angles, the target efficiency was quite high and the non-target efficiency was considerably lower. At higher angles, this trend is switched. There exists an angle value where both efficiencies are maximized and in this particular machine it is around 34 degrees. It does not follow, however, that an angle of 34 degrees is optimal for all other RE Rollers because this parameter is based on machine and process settings.

The non-target efficiency is found to be very high and unaffected by increasing feed rates while the target efficiency slightly declines from a value close to 1. These results were unexpected as the RE Roller is typically portrayed as a low volume separator. Because the efficiencies are above industry standards at high feed rates, the separation process can move to handle larger volumes.

5.3 Future work

While this thesis provides insight to the performance of PET plastic and aluminum separation on the Rare Earth Roller by experimentation, much more can be done to explore the behavior of different materials on a theoretical level. The proximity effect model which was discussed earlier touches upon how particles interact and interfere with each other.

For future work, a model for splitter device interference can be developed and tested to determine whether the interactions with the splitter significant affect the separation performance. The splitter thickness is not negligible and by closely examining the physical separation, we can find several particles bouncing off the splitter. Some particles end up in the correct compartment after such interactions while others are thrown off their path and fall into the incorrect compartment.

If a normal distribution for both target and non-target output streams is assumed, a model can be produced to illustrate the overlap between the outputs. The splitter acts in this overlap region and determines how much of non-target material is found in the target output and vice versa.

To better understand the separation processes employed in the recycling industry, more tests can be done with the Rare Earth Roller or similar experiments can be reproduced on other magnetic separators.

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