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Designing and Assessment of a Dry Based Physical Separator for Recovery of Metal Fractions from Used Tyres

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Abstract: ***Sustainable resource recovery and recycling forms an integral part of a developed and developing economy. Energy hunger and record hike in fuel prices coupled with market competition in the cement industry has provided many opportunities for the application of alternative fuels from waste materials. Scrap tires as an alternative fuel is gaining grounds in comparison with coal and furnace oil due to its low price and nearly parallel heating value (i-e 7200 – 8300 kcal/kg) coupled with the ease of its availability and currently low prices. Scape tyres used as a fuel not only give heat energy but also reduces tonnage of waste produced. To get the continuous feed of TDF, tyres are shredded before combustion which results in combustible (e.g. Rubber) and non-combustible (steel wires) products. Many solutions are in use to separate the non-combustible steel wires such as the use of magnetic separator however varying size of the steel wires and that of the polymeric combustible material makes it difficult to achieve the complete separation. This is mainly due to the wire entanglement and trapping of combustible material as well as clinging of small sized particles in both separation phases, resulting in poor separation efficiency. This results in loss of combustible material as well as produces a low quality steel for metal recyclers. In this work a dry separation method with no pre and post treatment is proposed. Experiments carried out at different operating condition resulted in determination of optimum reduced particle size of 4.0mm for the feed material which gave the maximum separation efficiency of 87.2% when the particle bed height was set at 60mm with the partition gap opening of 05mm. These optimum conditions resulted in enhancing the purity of the steel wire which is intended to generate good revenues and a valuable source of raw materials for the local steel industry.***

Keywords: TDF, bed height, steel wires, separation efficiency**,** grade, recovery

1. Introduction

The invention of wheel revolutionized the human life especially by the invention of pneumatic tyres. Pneumatic tyres were first invented by Robert Thompson in the middle of the 19th Century, which was first used for driving horse carts. In 1839 Charles Goodyear made first vulcanized tyre. Vulcanization is the reinforcement of rubber layers overlapped on each other. Vulcanization made rubber tyre to convert in hollow tube consisting of nylon threads, steel and elastomers [1]. André Michelin, and Edouard both brothers working on tyres, made it possible in 1888 to use air filled tyres for the first time in automobiles. The estimated production of tyres produced worldwide is about 100 millions [2]. A tyre is ready to be replaced by a new one when it covers a distance of 50000 km. The life of tyre is proportional to driving behaviour and surface roughness [3]. The predicated rate of vehicles running on road in Great Britain is from 17 to 39 percent for period a span of fifteen years that ends in 2012 [4]. If there is no increase in the life time of tyre the probable discarding of scraped tyres will increase proportionally. Assuming that there are no major increases in tyre longevity, the number of worn tyres requiring disposal would be expected to increase accordingly. As more and more tyres reach their worm out life so it becomes an important issue to treat them in accordance to their increased rate of replacement. So to overcome this problem new procedures and processing methods of re-cycling are developed to cope with this rapid increase of scrap tyres. Only a negligible amount of tyre is lost on the time of disposal, which shows that a worn tyre and a fresh one are similar in physical properties as well as in chemical [5]. Waste tyres production and its disposal have given rise to environmental problems. To deal with this waste different ways and techniques has been introduced to control its impact on our environment. Keeping this in view a study is made to convert this waste for its beneficial use.

Modern tyres have much life than before but the number of cars running on roads and the average distance cover by a car is also increasing hence the rate of scrap tyres is also increasing. According to the Scrap Tire Management Council, the standard assumption for waste (also known as scrap) tires are generated at a rate of one tire per person per year [6]. Scrap tyres production in such a high rate has created many environmental problems.

Approximately 1 billion tires are replaced with new one as they reach the end of their useful lives every year worldwide. The disposal of ELTs in environmental friendly and productive ways remained the top priority of tire business. Various regional efforts by governmental authorities, the tire industry and individual manufacturers are currently underway to address the issue of ELTs, and good progress is being made. ELT recovery provides cost-effective and environmentally sound energy for several industries. It also provides innovative materials for civil engineering projects. ELTs can replace other limited natural resources. ELTs have a variety of uses and they are increasingly being viewed as a resource instead of a waste. Environmental issues continue to be a driving force behind ELT recycling, and as the recycling industry develops with legislative and infrastructure support, it is becoming clear that there can be significant benefits.

The recycling of the residues resulting from energy recovery processes as applied to scrap tyres has received increased interest in recent years mainly as a source of alternative fuels. Tyres represent a low cost, high availability, fuel source that is initially manufactured from high cost raw materials. The recovery of combustible and non-combustible materials can offset the cost of energy requirements for the burning process.

2. Literature Survey

McBirde, *et al.*, carried out his investigation on the use of a large vertical venture separator for the removal of tangled steel and rayon fibres from crumbed rubber product of recycle tyres. It was found experimentally that a classically designed venture can untangle the synthetic fibre from tyres steel wires. With an adequate air flow venture was able to hold the large size particles in the throat area, allowing the clean steel wires to pass straight through. **(McBirde, *et al*, 2005). [7]**

Zhang, ***et al.*,** used the two drum eddy current separators (ECS) for recovering the nonferrous metals used in the recycling industry. Conducting particles were accelerated due to the eddy current force originating from an interaction between the induced magnetic moment in the particles and the applied magnetic field. Non-conducting or poorly conducting particles however fell down close to the drum. The development of ECS in their research was oriented towards separating the small size particles and different metals alloys with a high degree of selectivity. One of the latest advances in this category of separators is the use of two-drum ECS, High-Force ECS (HFECS) developed by International Process Systems, Golden, CO. The basic concept behind these techniques is use of staged separation where most of the big particles are separated out in the first magnetic drum while the small particles are deflected further by the second magnetic drum which spins fast in an opposite direction to the first drum **(Zhang**, ***et al*, 1999). [8]**

Lungu presented a technique for separation of metallic nonferrous particles from two component nonferrous mixtures using a new type of dynamic eddy-current separator with permanent magnets. The so called Angular Drum Eddy-Current Separator (ADECS) consists of a horizontal rotary drum covered with permanent magnets, alternately N–S and S–N oriented. The axis of the drum and the direction of displacement of the belt made a certain angle, depending on the physical properties of the particles subjected to the separation process. The separator worked on the principle of jump effect of the strongly conducting particles that assumed different trajectories in the active zone of the field. The ADECS successfully separated wastes containing conductive non-ferrous and non-conductive particles or strongly conducting and poorly conducting nonferrous particles **(Lungu, 2005). [9]**

Schlett*et al* has worked on a new type of eddy-current separator with the view of separating particles from a mixture with dielectric particles and/or metallic particles with different physical characteristics. The efficiency of the new separator was examined for the Cu–Pb, Al–rubber and Cu–Al mixtures. For different kind of mixtures the eddy-current separator with magnetic disc was one of the most efficient separators for metal–dielectric mixtures. The theoretical suppositions referring to the functioning of the device based on the jump effect were confirmed in the experiments. Even for the Al–Cu mixture, for which the conventional separators are not efficient, the separation results were good. The decreasing of the G (Weight) and R (is the mean value of the radius of the particle) for high values of the rotation were due to the effect of collision and the train of the dielectric particles from the metallic ones, during their violent jumping. A small number of dielectric particles arrived in the collector with metallic particles. For a revolution number greater than 1200 rev/ min, the G and R were observed to decrease. This can be explained by the electromagnetic forces which act upon the wires of Cu increasing the jumps from the support **(Schlett, 2002).[10]**

3. Problem Statement

In pursuit of cheaper energy sources scrap tyres as source of fuel has caught the attention of local cement industry. Two types of tyres (Nylon and Paswan) are currently in use. The former has rubber and rayon fibres and no steel wires while the latter has steel wires to enhance the structural integrity. Paswan is a good option for TDF due to its abundance availability and comparative low price in comparison with Nylon tyres.

Due to the ease of handing, continuous and controlled feeding, tyre shredding is preferred over the use of whole tyre as an energy source. However this poses significant separation problems for the resulting TDF. The problem looked into this work will include the minimization and/or removal of trapped and/or adhered tire pieces in the waste steel wires which could potentially become a valuable reuse option. Solution to this problem will include the designing of a dry based physical separator that will enhance the separation efficiency of the tire pieces and steel wires in continuous particle size range.

4. Materials and Methods

In this research work vertical vibrating separator has been introduced after detailed survey of separators for steel wires recovery from shredded tyres. Vertical vibratory separator is a square shaped table with solid base/ foundation. Metallic square shape plate thickness is 5.0mm. Square shaped thick steel plate is placed on four strong springs at each corner. Upper end of the springs is around the pipe welded with the table. Similarly lower end of the springs is inside the pipe welded on the strong foundation. When table plate is mounted on springs alone and free from vibrating source it can be vibrate with hands easily. For linear motion control at each corner of the plate two concentric pipes with 0.5mm clearance are welded with base/foundation and metallic plate. Linear motion control system allows vibrator to vibrate only in up and down direction and restrict its movement in any other direction.

Vibration to the system is provided by an assembly consisted of an electric motor and pulley on a crank shaft. One end of the crank is connected with table and other with crank assembly mounted on the solid foundation. A pulley on the crank shaft is connected with the pulley on the electric motor through a V-belt. When electric motor gets start it rotate crank shaft with help of v-belt the crank shaft pull and push the table as it rotates. During this time motion of the table is controlled linearly with the help of concentric pipes welded at each end. Table vibrates only in vertical direction. For analyzing sample L-shaped cell was constructed from transparent plastic sheet of 3mm thickness over the vibrating separator. Vertical part of L is used as storage. In this part material for analysis is stacked before analyzing. Also this part is provided with a scale measuring bed height. It has a sliding gate whose opening can be adjusted and when material is analyzed for separation tyre rich product flow P-1 flows down in collecting vessel.

Sample Preparation

Large pieces of tyres were acquired from the market, washed and air dried for any contamination. Its size reduced to 15mm with Rasper and further size reduction carried out with grinder. Three samples of sizes 2.0mm, 4.0mm and 6.0mm prepared.

A sieve analysis (or gradation test) is a practice or procedure used to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performance in use. Sieve analysis for the sample was carried out to find out size distribution of the sample for experimental analysis. 40gm sample was taken for sieve analysis for a constant time period of 10minutes. After sieve analysis retained on each sieve was fined out. The data for all three samples is shown on graphs below

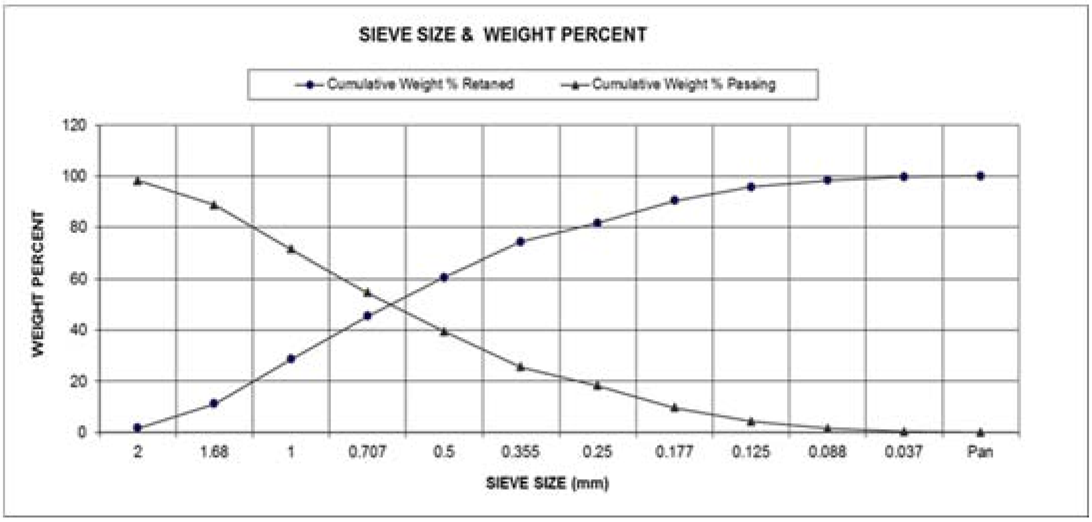

Figure: Sieve size and weight percent (2.0 mm)

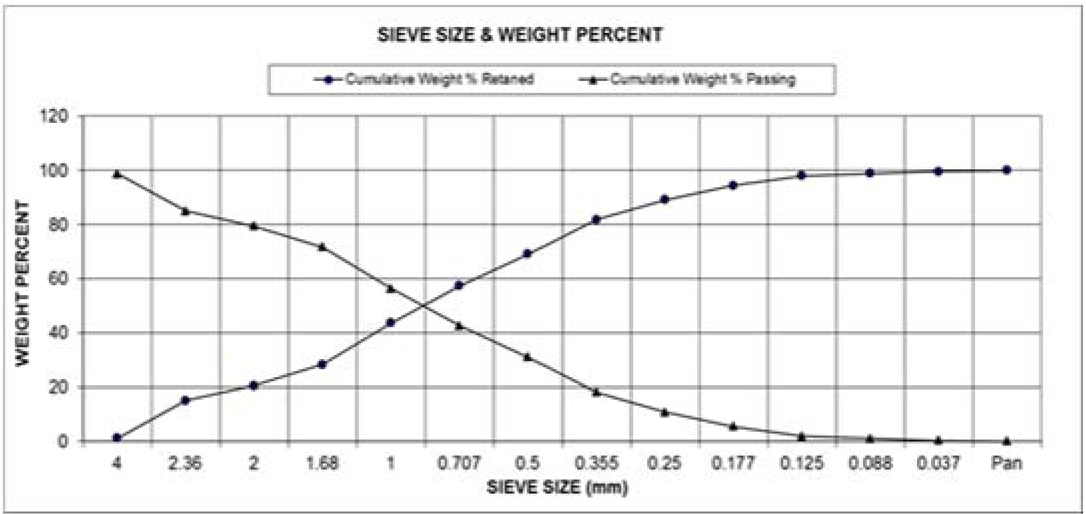

Figure: Sieve size and Weight Percent (4.0mm)

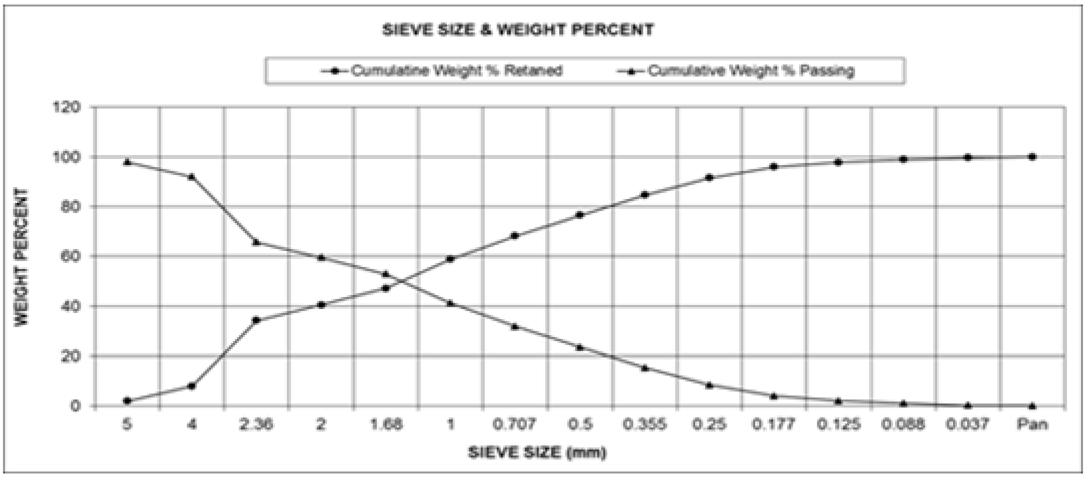

Figure: Sieve size and Weight Percent (6.0mm)

5. Results and Discussions

Experimental study was carried out on vertical vibrating separator. Shredded and grind tyre rubber was fed as feed for separation. Rubber and steel wires were collected separately and then analyzed. During analysis various parameters like separation efficiency, recovery and grade was calculated.

5.1 Experimental Procedure

This is a batch wise experimental process for a specific quantity of sample put in the main chamber. Vibrator was operated for a specific amount of time and two products were produced at the end of each experimental run. For each experiment the feed material was placed in the main chamber (vertical part of the L-shaped cell). L-shaped chamber is scaled to a length of 150 mm. During experiments bed of the material in chamber kept varying and vibrator was set to vibrate for a specific time period. In every experiment two different products were produced which were different in composition (rubber steel wire mixture percentage). Two products produced were named p-1 and p-2. For analysis as three different samples were prepared for the experimental analysis to show the maximum recovery of metal based on their size and separator bed height. Five runs for each of the three different sample sizes were carried out. In every experimental run a specific quantity of sample from feed, product P-1 and product P-2 was analyzed to find out feed and product composition needed for our findings as will be shown in the tables and graphs in this chapter later.

5.2 Analysis of 2.0mm Size Sample

For analysis 2.0 mm size sample was put in main chamber and bed height was kept to a level of 20 mm. Level was carefully watched from side with the scale on the chamber showing height of bed. Sliding gate opening was adjusted at 5.0 mm. The opening was enough for material to slide and flow towards the end where it is collected. Vibrator was set to vibrate for a constant time period of 20 minutes. As two separate products were collected from the cell which was named P-1 and P-2. Lower density product collected from the exit steam was named P-1 while product collected from inside the chamber named P-2. Product P-1 was rich in tyre rubber. Each time various parameters like separation efficiency, grade and recovery were observed for each run. Table 3.1 shows separation analysis for the sample size of 2.0mm. For analysis of feed, product p-1 and product p-2 20gm representative sample was taken. In the below table analysis are based on the results obtained after analyzing 20gm sample for analysis of feed, product P-1 and product P-2.

Table 5.1: Shows separation analysis of 2.0mm sample

Bed Height(mm)		20	40	60	80	100
Sample wt(gm)		505.39	10396	16026	2231.5	28823
Feed	Steel	111.2	233.9	368.6	502.1	634.11
	Rubber	394.2	805.67	12344	1729.4	22482
Product P-1	Steel	38.92	53.8	44.25	80.34	139.5
	Rubber	390.68	798.65	12222	159329	19358
Product P-2	Steel	72.28	180.1	324.34	421.76	494.6
	Rubber	3.52	7.02	12.2	136.11	312.39
	Total wt P2(gm)	75.8	187.12	336.55	557.87	807
	Grade	95.36	96.25	96.37	75.60	61.29
	Recovery	65	77.00	87.99	84.00	78.00
Separation Efficiency		50.25	59.15	59.15	59.98	52.39

Also the graphs show separation efficiency analysis for 2.0mm sample size. First bed height was kept 20 mm and then for five runs with 20mm increase for each run. This graph clearly shows that separation efficiency has a direct relation with bed height up to 60mm. As bed height increases from 60mm to 80mm and then 100mm separation of the separator has decreased. This shows that maximum separation can be achieved with bed height is kept at 60mm. For each run gate opening is kept constant at 5.0mm.

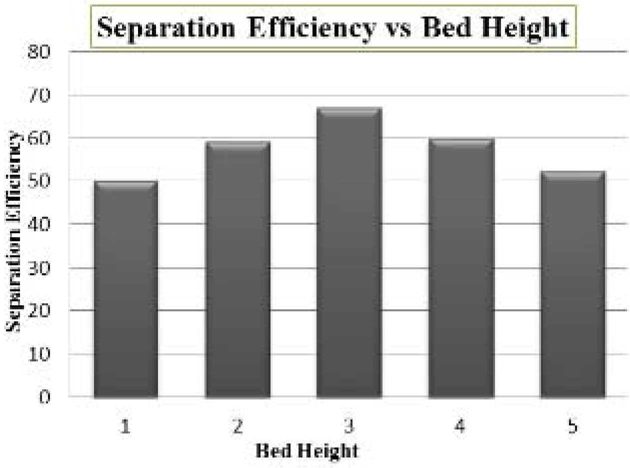

Figure 5.1: Separation Efficiency vs Bed Height (Sample size 2.0mm)

Recovery drawn verses bed height showed continued increase when bed height becomes 60mm and then recovery is on decline as bed height further decreases from 60mm.

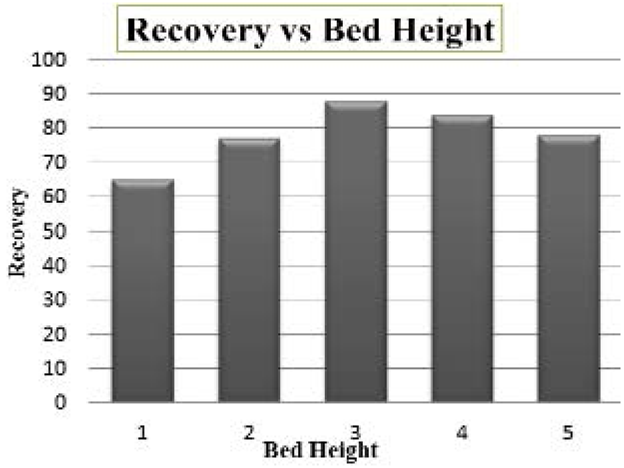

Figure 5.2: Recovery & Bed Height (2.0mm)

Grade during this separation process remained high as long as particle loading in cell is low i-e when bed height is at 60mm and shows decrease as bed height further increased from 60mm.

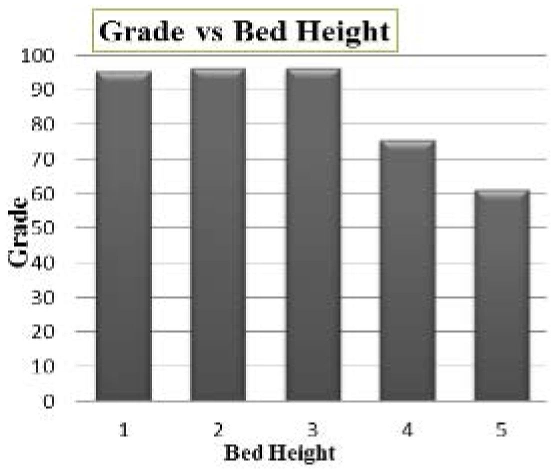

Figure 5.3: Recovery and Bed Height (sample size 2.0mm)

5.3 Separation Analysis for 4.0mm Sample size

Analysis for 4.0mm sample size was carried out in the same manner as for 2.0mm sample size. First the bed height in the sample was kept at 20.0mm and the separator operated for the same time period of 20 minutes. Two products P-1 and P-2 achieved at the end of this separation analysis. The same procedure was repeated for the next consecutive runs with changing bed height. A 20 gm sample for analysis of feed, product P1 and product P-2 was analyzed data produced from analysis was put in the table. Separation efficiency, grade and recovery were found for each run and are shown in the table below.

Table 5.2: Separation analysis for 4.0mm sample size

Bed Height(mm)		20	40	60	80	100
Sample wt(gm)		534.7	994.1	1434	2031	2635.7
Feed	Steel	117.6	223.7	329.8	457	593.00
	Rubber	417	770.3	1104	1574	2042.6
Product P-1	Steel	38.8	49.21	36.3	86.9	136.39
	Rubber	405.5	805.1	1082	1416	1761.3
Product P-2	Steel	78.8	174.5	293.5	370	456.61
	Rubber	12.1	14.42	21.95	158	281.4
	Total wt P-2 (gm)	90.9	188.9	315.47	528	737.98
	Grade	86.69	92.37	93.04	70.10	61.87
	Recovery	67.01	78.00	88.99	81.00	77.00
Separation Efficiency		65.16	81.52	87.22	72.88	66.39

Separation efficiency calculated at each experimental run plotted against bed height. From the graph it is clear that separation efficiency increases as bed height increases. Separation efficiency is maximum 87.22% when bed height is at 60.0mm. It is decreases as bed height further increased from 60.0mm.

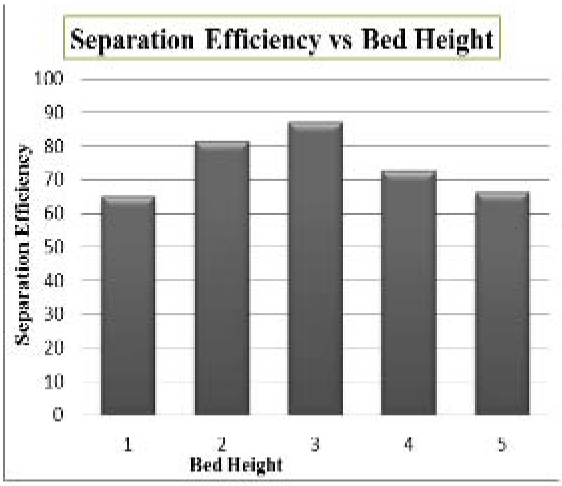

Figure 5.4: Separation Efficiency vs Hed Height(4.0mm)

Recovery is the amount of metal recovered in this separation process. From the results produced during the separation process a graph is plotted between recovery and bed height. In this too like separation efficiency recovery is on increase when the bed height becomes 60.0mm and then it is on decrease as bed height is further increased.

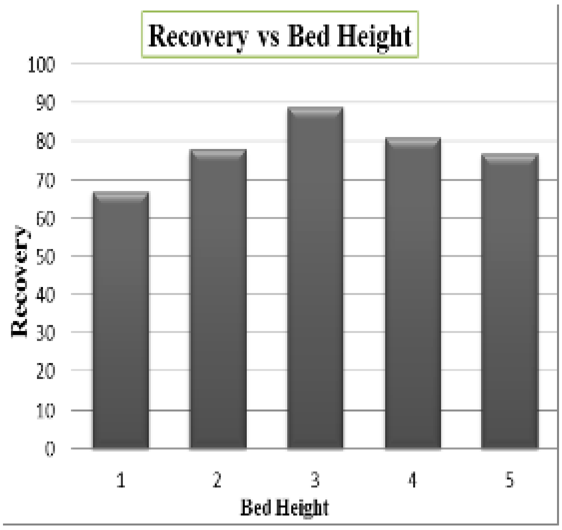

Figure 5.5: Recovery vs Bed Height (4.0mm)

Grade which shows how pure the product that we got at the end of each experimental run. In all this process grade is calculated for the product p-2 which wire rich product. From the graphs it is clear that as long as particle load on the cell is low grade is high and as load is increased from an optimum level of 60.0mm. Grade is decraesed as is clear from the garph shown.

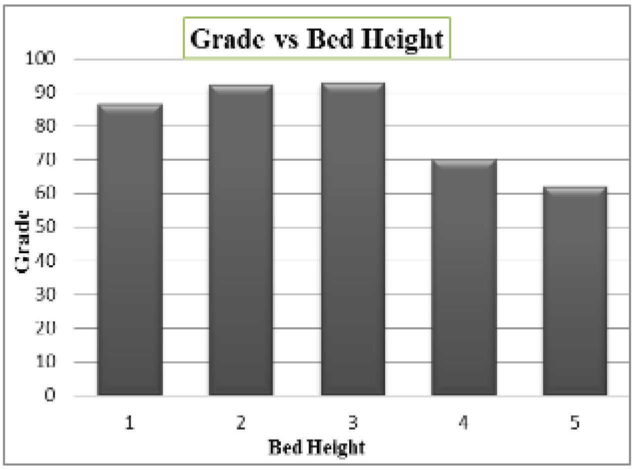

Figure 5.6: Grade vs Bed Height (4.0mm)

5.4 Separation Analysis for 6.0mm Sample size

A batch wise separation process was carried out for the sample size of 6.0mm. Sample for analysis was put in the cell for the separation with initial bed height of 20.0mm. Vibrating separator was set to vibrate for a constant time period of 20 minutes. At the end of the separation process two different products were collected separately. Product P-1 received in the vessel flowing down in the horizontal part while the product P-2 is recovered from inside the cell. A sample of 20gm from feed, prodcut p-1 and product p-2 was analysed to fined out the tyre and wire composition in each one. Data produced from this process put in the table and is shown in the table below

Table 5.3: Separation analyses for 6.0mm sample size

	Bed Height(mm)	20	40	60	80	100
	Sample wt(gm)	487	975	1431	1937	2421
Feed	Steel	107	220	329	426	539.89
	Rubber	380	756	1102	1511	1881
Product P-1	Steel	30.2	43.9	46.01	93.7	140.4
	Rubber	375	746	1056	1320	1554
Product P-2	Steel	77	176	283	332	399.5
	Rubber	5.82	9.74	46.12	191	326.8
	Total wt P-2 (gm)	82.9	185	329.06	523	726.3
	Grade	92.93	94.74	86.00	63.56	55.00
	Recovery	71.8	80.00	86.02	86.02	74.00
	Separation Efficiency	70.77	78.97	82.41	68.16	61.14

Table shows gardual trends of increase at start and decrease later in separation efficiency and recovery in this process. However a high valves for garde produced at lower bed heights and its value decreases as bed height is increased.

Separation efficiency is plotted against bed height which shows that as long as bed height is some where at the mid of the five runs separation is high. High valve for it is achieved when bed is at 60mm and then gradual decrease.

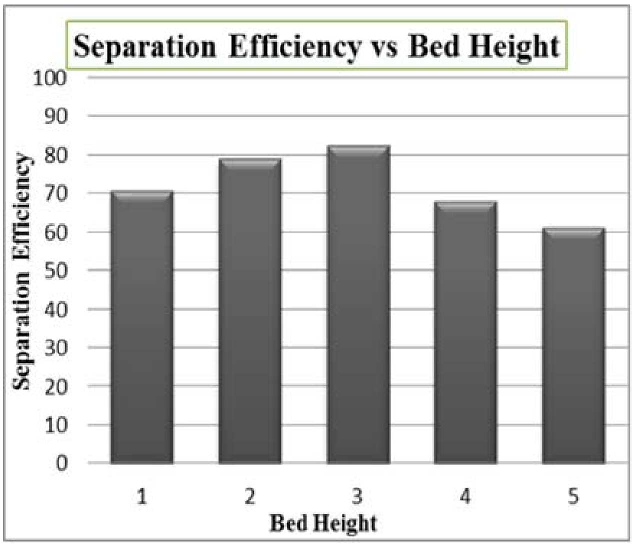

Figure 5.7: Separation efficiency vs Bed Height (6.0mm)

Also recovery which is the total amount of metal recovered during is separation process plotted against bed height. Recovery is on increase as bed height is increased. At 60mm bed height recovery reached its maximum valve of 86.02%. Then a decrease in its value is shown due to further increase in bed height.

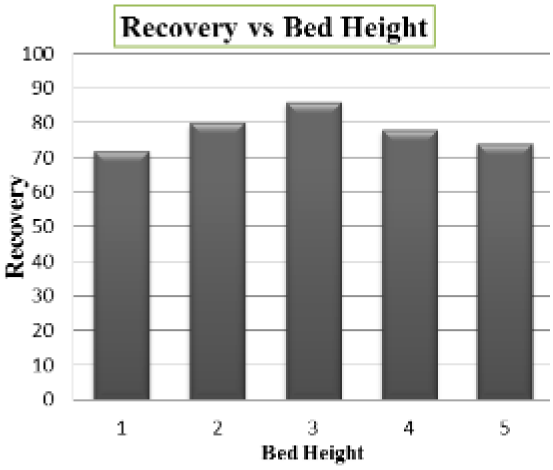

Figure: Recovery and Bed Height (6.0mm)

Grade which is the purity of the recovered product plotted against bed height. At start grade is high and as bed height is on increase grade is decreasing and reaches at a lowest valve of 55% when bed height is 100mm.

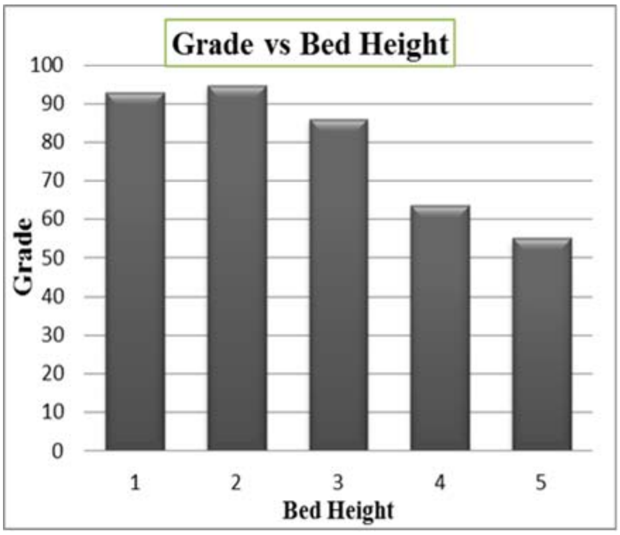

Figure: Grade and Bed Height (6.0mm)

6. Conclusion

This research is intended to look into enhancing the dry based separation of TDF. A comparative study of different separation process and techniques in practice was studied. After completing the investigation regarding different type of separators for shredded tyres, a vertical vibrating dry based physical separator was designed and fabricated. A sample was prepared for carrying out experiments to find out the separation efficiency of this vertical vibrating separator. Five runs with step changes in bed height of 20mm for each of the three different size samples was carried out. Separation efficiency, grade and recovery for these three different size samples was found and results showed that the enhanced particle grade can be achieved when the particle bed height is set at 20mm while the enhanced recovery was seen when the bed height was set at 80mm. Maximum separation was achieved when the particle bed height was set at 60mm for the mean particle size of 4.0mm.

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