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Development and Performance Analysis of a Mini Twin-Shaft Shredder for Efficient Polyethylene Terephthalate (PET) Bottle Recycling

ABSTRACT

Polyethylene terephthalate (PET) stands out as the most widely recycled plastic globally. However, in the Philippines, the processes associated with PET recycling, particularly the transportation of PET bottles from collectors and consolidators to processing plants, demand significant time, monetary resources, and effort due to the lack of appropriately sized shredder machines in local junkshops to reduce bulkiness. As a response, this study aimed to design a mini twin-shaft PET bottle shredder. The design took into account the constraints and prerequisites of local junkshop proprietors, municipal and barangay local government units, and non-government organizations.

The machine was comprised of five essential components: the hopper, shredding chamber, power transmission, prime mover, and frame. Post-consumer PET bottles were employed as test materials for experimentation at different treatment speeds: 30, 40, and 50rpm. The experimental layout followed a completely randomized design (CRD). Performance metrics, including shredding capacity, shredding efficiency, and energy demand, were scrutinized based on shaft speed alterations through analysis of variance testing. Additionally, comparison among means was executed using the least significant difference (LSD) method, with a significance level of 5%.

Results indicated that the highest shredding input capacity of 34.07 kg/hr was attained at a shaft speed of 50rpm, along with a shredding efficiency of 91.3%. The presence of unshredded materials was identified as the primary cause of device inefficiency, constituting 6.44% of the total test materials input. The energy demand was calculated at 0.132 kW-hr/kg. The resulting product dimensions primarily ranged between 25-50mm. A cost analysis demonstrated that the machine would need to shred a cumulative 6,889kg of PET bottles to reach the breakeven point, given a custom rate of Php7/kg (\$0.12/kg). The initial investment cost of Php124,383 (\$2,194.71) could be recuperated in a mere 1.91 years, yielding an added net income of Php210,000/yr (\$3,705.40/yr) for PET collectors and/or consolidators.

Keywords: PET (Polyethylene Terephthalate), Plastic Recycling, Plastic Shredder, Twin-shaft Shredder, Cost Analysis, Market Feasibility

1. INTRODUCTION

The Philippines annually imports a total of 24,000 metric tons of PET materials, encompassing resin, preforms, sheets, and finalized packaging products. These materials are subsequently converted into 22,592 metric tons of bottles and containers for both food and non-food applications, as well as packaging materials for electronic products. In 2001, the generated amount of industrial and post-consumer waste reached 5,040 metric tons, resulting in a 21% recovery rate of PET plastic waste. The primary participants involved in

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23 the collection and retrieval of PET industrial and post-consumer waste include junkshops,
24 PET consolidators, and PET recyclers [6][10].

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26 To date, only half of PET waste is globally recycled, while the remainder is incinerated or
27 dumped in landfills, rivers, and oceans. To address the continuously escalating rate of waste
28 generation, the government sector promotes the collection, retrieval, and recycling of waste
29 such as PET bottles. One crucial step in the bottle recycling process involves size reduction,
30 wherein the shredding process is employed. Shredding yields smaller pieces of coarse,
31 irregularly shaped plastic flakes, which can subsequently undergo further processing. Based
32 on conducted interviews at a local junkshop, manual volumetric reduction demands
33 excessive time and labor. Furthermore, no machines have yet reached the junkshops to
34 facilitate the reduction of their plastic collections.

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36 Local junkshops lacking the capital to purchase trucks for hauling their products to plastic
37 melting factories rely solely on truck rentals. The expenses for transportation range from Php
38 9,000.00 (\$158.80) to Php16,000.00 (\$282.32) per load based on volume. A ten-wheeler
39 truck can accommodate 2 to 2.7 tons of uncompressed PET bottles, depending on the
40 loading strategy, and around 6 tons when the bottles are pressed, irrespective of the loading
41 type. Pressing and shredding bottles enhance material density, thus increasing the volume
42 the truck can carry in a single trip. Additionally, shredded PET bottles command a higher
43 selling price than those that haven't undergone the shredding process. Consequently,
44 reducing the size of PET bottles before transporting them to processing centers reduces
45 expenses and processing time, ultimately boosting profits for local junkshop owners.

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47 Junkshops could avail themselves of a plastic shredding machine offered for free by a plastic
48 melting factory, provided the quota for plastic volume delivery within a specific timeframe is
49 met. However, for local junkshop owners, the terms set by the melting factory are
50 challenging to meet due to limited time and capital. Consequently, no junkshop in the vicinity
51 has yet accepted this demanding offer. The general objective of the study was to develop a
52 mini twin-shaft PET bottle shredder. Specifically, the study aimed to design this machine
53 using locally available materials, fabricate it using local manufacturing technology, evaluate
54 the device's performance in terms of shredding capacity and efficiency, determine its energy
55 demand, and analyze the associated cost of its usage.

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57 **2. MATERIAL AND METHODS**

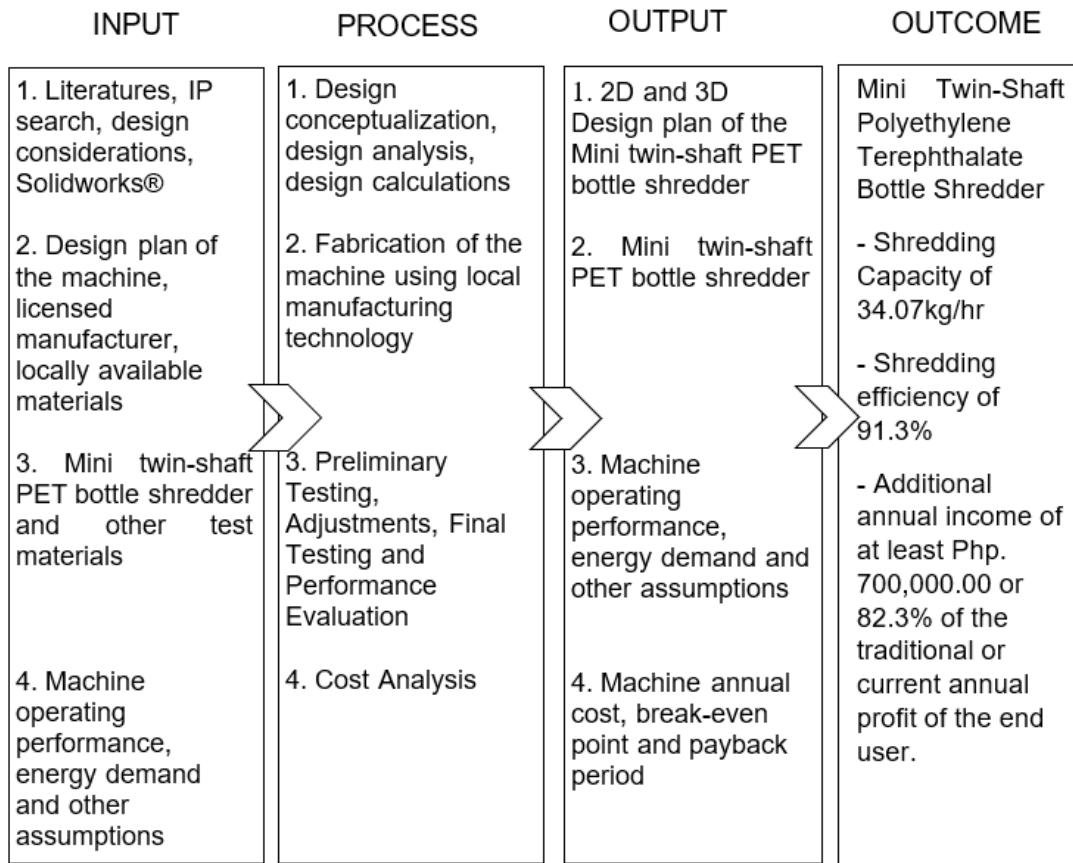
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59 **2.1 Conceptualization of the study**

60 The conceptualization of the study took into consideration the input of local junkshop
61 owners, municipal and barangay local government units, as well as non-government
62 organizations during interviews. Feedback revealed that certain junkshop owners tend to
63 compress PET bottles using vehicles before delivering them to processing plants in order to
64 reduce bulkiness. Others refrain from doing so due to a lack of available pressing areas,
65 vehicles, and the labor-intensive nature of the process. Municipal and barangay local
66 government units emphasized waste disposal as a major concern, with some spending 30 to
67 50 million pesos per month solely on waste transportation. Non-government organizations
68 reported difficulties in advancing their recycling initiatives due to the absence of machinery in
69 the locality and the local market capable of facilitating further plastic processing to create
70 more products from PET bottles. Consequently, to address these challenges and enhance
71 the economic and environmentally friendly aspects of recycling, a mini twin-shaft PET bottle
72 shredder was developed using locally available materials and machine technology essential
73 for recycling purposes.

74

75 Figure 1 illustrates the study's conceptual framework, following the input-process-outcome
 76 approach. The framework is primarily built upon the study's overarching objective, which is
 77 the development.
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79
 80 **Fig. 1. Conceptual framework of the study**
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82 **2.2 Design concept of the machine**

83 The design of the PET bottle shredder was guided by the daily quantity of PET bottles
 84 amassed by PET bottle collectors and consolidators. The shredder consists of five main
 85 components (Figure 2): the hopper, shredding chamber, power transmission system, prime
 86 mover, and frame. The construction materials employed for the machine encompassed an
 87 electric motor, v-belts, v-pulleys, spur gears, angular bars, screws, ball bearings, high tensile
 88 bolts and nuts, G.I sheet, MS plate, high carbon steels, and shafts.

1	Hopper	4	Electric motor
2	Shredding Chamber	5	Frame
3	Transmission System		

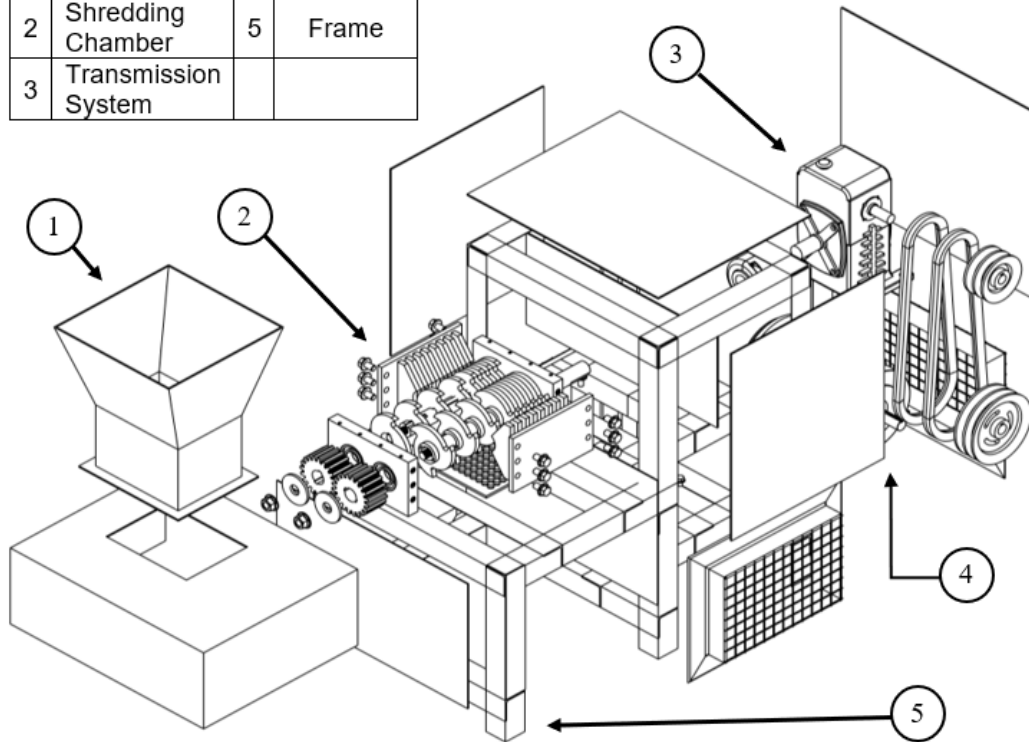


Fig. 2. Mini twin-shaft PET bottle shredder exploded view

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2.3 Design of Major Components

2.3.1 Hopper

The material chosen for the hopper was a G.I steel sheet, specifically designed to accommodate the materials being fed into the shredder. It also functions as a guard to prevent shredded materials from exiting the shredding chamber and scattering. The dimensions of the hopper were calculated utilizing the equation for the volume of a truncated pyramid, as presented in the equation 1.

$$V = \frac{1}{3}(A_1 + A_2 + \sqrt{A_1 + A_2}) \times h \quad (1)$$

101

$$\text{where: } A_1 = S_1^2$$

$$A_2 = S_2^2$$

104

$$\text{Tan } \theta = \frac{h}{\frac{S_1 - S_2}{2}} \quad (2)$$

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where: V : Volume of the truncated pyramid
 A_1 : Area of the upper base, mm²
 A_2 : Area of the lower base, mm²
h : height of the truncated pyramid, mm
 S_1 : Width of the upper base, mm
 S_2 : Width of the lower base, mm
 θ : angle of inclination of the hopper side,

114 The G.I. steel sheet possesses a yield strength of 470MPa. Using this value along with the
115 estimated load that the hopper will bear, the thickness of the G.I. steel sheet was determined
116 utilizing the fundamental equation:

$$117 \sigma = \frac{P}{A} \quad (3)$$

119 Where: σ : Allowable stress, MPa
120 P : load, N
121 A : Area, mm²
122

123 2.3.2 Shredding Chamber and Blade Assembly

124 This component serves as a holder, protector, and enclosure for the blade assembly, which
125 comprises the blades and shafts. Designs and calculations were performed on a per-part
126 and/or component basis.

127 2.3.2.1 Shredder blade with spacer

128 The plastic bottles are shredded through the action of the blade assembly. According to the
129 research conducted by Villafaña et al. [11], the stress at the average breaking point of PET
130 falls within the range of 140MPa to 210MPa. The analysis of blade force is determined by
131 the shearing force required to fracture the bottle and can be computed using the following
132 equation.

$$133 \frac{F_{sh}}{A} = \frac{S_{ut}}{F.O.S.} \quad (4)$$

134 Where: F_{sh} : shearing force, N
135 A : Area of contact of blade to the material to be cut, mm²
136 S_{ut} : Yield strength of PET bottles, MPa
137 F.O.S. : Factor of Safety
138

139 The blade assembly consists of eight pairs of three-toothed blades. Because of the
140 intermeshing action of these blades, a gap between them is necessary. Therefore, distance
141 rings, with the same thickness as the blades, function as spacers to maintain the required
142 spacing.

143 2.3.2.2 Shredder Shafts

144 The design of the shredder's shafts aimed to prevent bending. AISI 4340 steel was chosen
145 as the fabrication material. The shaft diameter was determined using the following equation:

$$146 d_o^3 = \frac{16}{\tau_d \pi} \left[\sqrt{(C_m \times M_B)^2 + (C_t \times T)^2} \right] \quad (5)$$

147 Where: d_o : diameter of the shaft, mm
148 τ_d : design shear stress, MPa
149 C_m : bending factor
150 M_B : bending moment, N.mm
151 C_t : torsion factor
152 T : torque, N.mm
153

154 2.3.2.3 Spur Gears

155 Gears were linked on the same side of the shaft to generate counter-rotation of the shafts.
156 The design and calculations of the spur gears were guided by PAES 306:2000. [4] (Table 1).
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Table 1. Spur gear calculations.

To obtain	Given	Equation
	Circular pitch	$\frac{\text{Circular pitch}}{\pi}$
Module	Number of teeth and pitch diameter	$\frac{\text{Pitch diameter}}{\text{Number of teeth}}$
Pitch diameter	Number of teeth and module	Number of teeth x Module
Number of teeth	Pitch diameter and module	$\frac{\text{Pitch diameter}}{\text{Module}}$
Tooth thickness of the pitch line	Module	1.5078 x Module
Outside diameter	Pitch diameter and addendum	Add 2 addendums to the pitch diameter
Minimum whole depth	Module	Coarser than 1.0583 module, 2.35 x module
Addendum	Module	addendum = module
Dedendum	Module	dedendum = 1.25xmodule
Clearance	Whole depth and addendum	Subtract two addendums from the whole depth
Center distance	Number of teeth of driver and driven gear, t_1 and t_2 Module	$\frac{\text{module}(t_1 + t_2)}{2}$

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167 2.3.2.4 Transmission System

168 This component was devised to fulfill the requisite low speed and enhance the necessary
169 torque during shredding.

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171 Given that the machine is anticipated to operate primarily in locations with available
172 electricity and doesn't require mobility for its functioning, an electric motor is the most
173 appropriate choice as the prime mover. The capacity of the electric motor utilized in the
174 machine was determined based on the computed torque applied to the blade assembly. This
175 calculation was performed using equations 6, 7, 8 and 9.

176

$$177 \quad T = F_{sh} \times D \quad (6)$$

178

179 Where: F_{sh} : shearing force, N180 D : distance from the center to the tip of blade, mm

181

$$182 \quad P = 2\pi TN \quad (7)$$

183

184 Where: P : Power, Hp185 T : Torque, N.mm186 N : Speed, rpm

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$$188 \quad N_1 D_1 = N_2 D_2 \quad [5]$$

189 (8)

190

191 Where: N_1 : Speed of the driver pulley, RPM192 D_2 : Diameter of the driver pulley, mm193 N_2 : Speed of the driven pulley

194 D_2 : Diameter of the driven pulley
 195 For the calculation of belt from PAES 301:2000 [5].
 196 (9)
 197

$$L = 2C + \frac{\pi}{2}(D_L + D_S) + \frac{(D_L - D_S)^2}{4C}$$

198
 199 Where: L : length of the belt (mm)
 200 C : distance between centers of pulleys (mm)
 201 D_L : diameter of the large pulley (mm)
 202 D_S : diameter of the small pulley (mm)
 203

204 Dimensions of tapered keys and keyways was based on PAES 304: 2000 [3].
 205

206 2.3.2.5 Frame Assembly

207 The shredding chamber, motor, and speed reducer were affixed to the frame constructed
 208 from angular bars, secured in place using bolts and nuts. The maximum bending moment
 209 was computed through the shear and moment diagram. Subsequent calculations for
 210 determining the dimensions of the angle bar employed in fabricating the machine were
 211 achieved using the following equation:
 212

213 For the calculation of allowable stress used equation 10.
 214

$$215 \quad \sigma_{\text{Allow}} = \frac{YS}{\text{FOS}} \quad (10)$$

216
 217
 218 Where: σ_{Allow} : Allowable Stress, MPa
 219 YS : Yield Strength or Ultimate strength, MPa
 220 FOS : Factor of Safety
 221

222 After the calculation of the allowable stress, compute for the section modulus using the
 223 equation:
 224

$$225 \quad Z = \frac{M_{\text{max}}}{\sigma_{\text{Allow}}} \quad (11)$$

226
 227 Where: σ_{Allow} : ultimate strength of the material, MPa
 228 M_{max} : Maximum bending moment, N.mm
 229 Z : Section modulus of angle bar, mm^3
 230

231 For solving the outer side and inner side of angle bar, the following equation was utilized:
 232

$$233 \quad Y = \frac{I}{Z} \quad (12)$$

234
 235 Where: I : Moment of Inertia, N.mm
 236 Y : Distance from Neutral Axis, mm
 237

238 The thickness of the angle bar was calculated using equation 13.
 239

$$240 \quad t = \frac{a-a_1}{2} \quad (13)$$

241

242 Where: t : Thickness of angle bar, mm
243 a : Outer side of angle bar, mm
244 a_1 : Inner side of angle bar, mm

245 **Table 2. Summary table of the properties of materials and factor of safety used in**
246 **different component**

Component	Material Used	Yield Strength, MPa	Factor Safety	of Allowable Stress, MPa
Hopper	G.I sheet	470	3	156.67
Shredder Blades with Spacers	AISI4340	710	1.5	473.33
Shredder Shafts	AISI 4340	710	3	236.67
Spur Gear	AISI 1045	530	3	265
Frame	ASTM A36	250	2.5	100

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248 **3. RESULTS AND DISCUSSION**

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250 **3.1 Description of the machine**

251 The manufactured machine (Figure 3) operated in a continuous feeding manner, allowing
252 materials to be consistently fed into the machine until all materials were shredded. In the
253 event of machine clogging, a reversal in the rotational speed direction of the electric motor
254 shaft was necessary to clear the shredding chamber.
255



256
257 **Fig. 3. Fabricated PET bottle shredding machine**

258
259 **3.2 Machine Performance Evaluation**

260 The machine underwent evaluation in terms of capacity, efficiency, and energy demand,
261 influenced by various shaft speeds (30rpm, 40rpm, and 50rpm). The obtained results were
262 subjected to statistical analysis using the Statistical Tool for Agricultural Research (STAR).
263 Figure 4 shows the collected shredder flakes.
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Fig. 4. Collected shredded flakes

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3.2.1 Machine Shredding Capacity

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It is the ratio of the weight of the input plastic materials minus the weight of unshredded plastic materials, divided by the total weight of the input plastic materials to the shredder, expressed in kg/hr, as determined by the following equation [1]:

273

$$C_i = \frac{W_i}{T} \quad (14)$$

274

Where: C_i : Input Capacity, kg/hr.

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W_i : Weight of Input Materials, kg

276

T : Operating Time, hr.

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The highest shredding capacity was achieved at the fastest shaft speed of 50rpm, with an average value of 34.07kg/hr. This was followed by 40rpm with a mean value of 21.69kg/hr, and the lowest capacity was recorded at the slowest speed of the main shaft, with an average value of 15.67kg/hr. Analysis of variance indicated that shaft speed had a significant impact on the machine's shredding capacity at a 5% level of significance.

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Table 3. Mean shredding capacity at various main shaft speed, kg/hr

Treatment RPM	Means
30	15.67 a
40	21.69 a
50	34.07 b

302

*Means with the same letter are not significantly different.

303

304 **3.2.2 Machine Shredding Efficiency**

305 It is the ratio of the weight of the input plastic materials minus the weight of unshredded
306 plastic materials, divided by the total weight of the input plastic materials to the shredder,
307 expressed as a percentage, as determined by the following equation:
308

309
$$Es = \frac{Ws}{Wi} \times 100 \tag{15}$$

310
311 Where: Es : Shredding Efficiency, kg
312 Ws : Weight of Shredded Materials, kg
313 Wi : Weight of Input Material, kg

314 The shredding efficiency of the machine, as detailed in Table 4, decreases with the rise in
315 shaft speed. At a shaft speed of 30rpm, the shredding efficiency was observed to be
316 94.64%, declining to 92.17% and 91.26% respectively, at 40 and 50rpm. Analysis of
317 variance indicated that shredding efficiency was significantly influenced by the shaft speed.
318 A comparison among means in Table 4 revealed that the shredding efficiency at the lowest
319 shaft speed of 30rpm was notably higher than at 40 and 50rpm. No significant differences
320 were observed when comparing 40 and 50rpm.
321

322 From the conducted sampling, it was found that at 30rpm, the least amount of unshredded
323 material (>50mm) was recorded, which had a considerable impact on the device's shredding
324 efficiency. It was noted that a screen placed below the shredding chamber served as the
325 medium for flake sizing, preventing flakes larger than 50mm from passing through the
326 screen holes. Nevertheless, a higher rpm of the shafts equated to a faster blade cutting rate
327 and feeding rate of PET bottles into the machine. Consequently, new materials being fed
328 forced some larger-than-50mm flakes to pass through the screen holes, leading to an
329 increased amount of unshredded materials at higher rpm. Conversely, a slower rpm of the
330 shredder shafts resulted in a more gradual feeding and cutting rate, allowing the blades
331 more time to lift materials longer than 50mm for another round of shredding instead of
332 forcing them through the screen holes.
333 Additionally, higher rpm of the shafts also led to a greater quantity of powder-like sized
334 flakes, which constituted the scattering loss and further impacted the shredder's efficiency.
335

336 **Table 4. Mean shredding efficiency at various main shaft speed, %**

Treatment RPM	Means
30	94.64 a
40	92.17 b
50	91.26 b

337 *Means with the same letter are not significantly different.

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339 **3.2.3 Energy Demand**

340 The amount of electricity consumed by the machine to process a kilogram of PET bottle
341 expressed in kilowatt-hour per kilogram [2].
342

343
$$Ed = \frac{Pi \times T}{Wi} \tag{16}$$

344
345 Where: Ed : Energy Demand
346 Pi : Power Input, (kW)
347 T : operating Time, (hr.)
348 Wi : Weight of Input Material, kg
349

350 Table 5 reveals that at 30rpm, the highest energy demand is observed, amounting to 0.205
 351 kW-hr/kg, followed by 40 rpm with 0.181 kW-hr/kg, and 50 rpm necessitating the lowest
 352 energy demand of 0.132 kW-hr/kg. The analysis of variance indicates that shaft speed
 353 significantly impacts the energy demand of the machine at a 5% level of significance. A
 354 comparison among treatment means reveals that the energy demand at 30rpm does not
 355 exhibit any significant difference compared to the energy demand at 40 rpm.
 356 These findings align with Fitzgerald G.'s study [8], suggesting that the rotor speed of low-
 357 speed high-torque (LSHT) shredders notably influences power consumption and device
 358 capacity. As rotor speed decreases, the specific energy required for waste processing tends
 359 to increase.

360
 361 **Table 5. Mean energy demand at various main shaft speed, kW-hr/kg**

Treatment RPM	Means
30	0.2047 a
40	0.1810 a
50	0.1317 b

362 *Means with the same letter are not significantly different.

363

364 **3.2.4 Cost Analysis on the use of the device**

365 The result of the cost analysis in Table 7 resulted to the cost of shredding equation as

366

367
$$CS = \frac{27,364.26}{V} + 3.03 \quad (17)$$

368

Where: CS : cost of Shredding, Php/kg

369

V : Volume of PET to be shredded, kg/yr

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371 With equation 17, the cost curve was drawn and shown in Figure 5. Generally, it was
 372 observed that the cost of shredding (Php/kg) decreased as the annual volume of PET bottles
 373 to be shredded increased. Table 6 presents the basic data and other assumptions used in
 374 the machine economic analysis. Information obtained from local junkshop owners in La
 375 Trinidad, Benguet revealed that an average of 60,000kg of PET bottles were collected in one
 376 year. With this volume, and at a rated capacity of the machine of 34.07kg/hr, it needed to
 377 operate about 1,765 hrs per year, equivalent to 220-250 days when it works 7-8hrs per day.
 378 At this volume (60,000kg/yr), the cost of operation, as computed using equation 16, would
 379 be Php3.49/kg (\$0.062/kg). Hence, using the machine for custom service operation, the
 380 custom rate of about Php7/kg (\$0.12/kg) could safely be assumed. At Php7/kg (\$0.062/kg)
 381 rate, operating the machine would break-even at 6,889kg/yr. Using the machine for custom
 382 operation (Php7/kg) for a volume of 60,000kg/yr, will yield a net income of Php210,000/yr
 383 (\$3,705.40/yr), resulting to a payback period of 1.9yrs.

384

385 **Table 6. Economic Analysis Assumptions**

Basic Data and Other Assumptions	Value	Unit
Investment Cost (Shredder)	124,383 (\$2194.71)	Php
Life Span	10.00	years
Input Capacity of the shredder	238.48	kg/day
Wage for the operator (Benguet Minimum Wage)	350.00 (\$6.18)	Php/day
Operator	1	Person
Average electric cost (Beneco Power Rate)	8.52 (\$0.15)	Php/kW
Operating Time	8.00	hrs/day

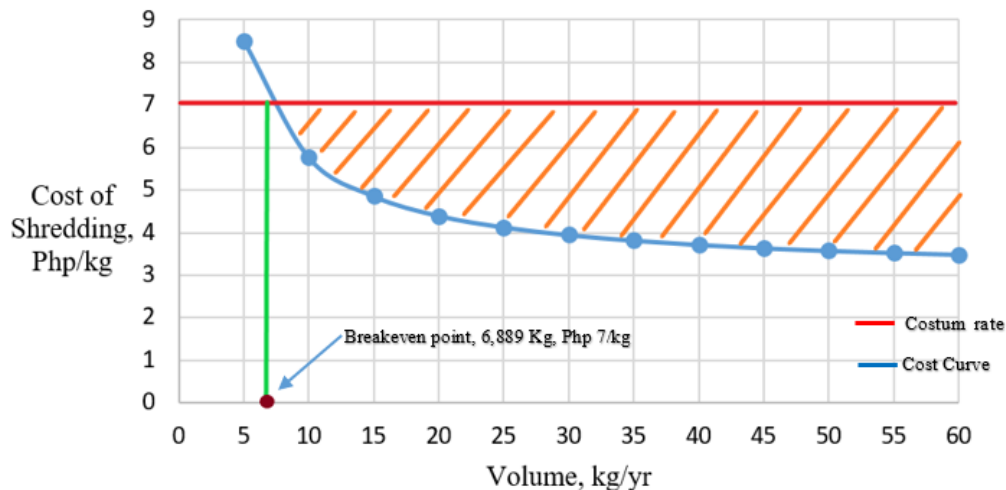
Annual Operation	252	Days/yr
Power consumption	2.5894	kW-hr
Ten-Wheeler van net Capacity	15	Tons
Ten-wheeler van volumetric capacity	55.00	m ³
Bulk volume of Shredded Pet Bottle	206.54	kg/m ³
Data obtained from Junkshop owners		
Average volume of collected PET bottle	60	Tons/yr
Average weight of whole plastics that can be hauled by ten-wheeler van	2.45	Tons/trip
Average transportation cost per trip	10,000.00 (\$176.45)	Php/trip
Bonus when the plants qouta (4 tons) is met for the rest of the PET bottle cargo per trip	2.00 (\$0.035)	php/kg
Average whole PET bottle cost	38.00 (\$0.67)	Php/kg
Estimated shredded PET bottle cost	1.3 times the average whole PET bottle cost of 30 percent more than the price of unshredded PET bottles	

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Table 7. Cost analysis of using the machine

Particulars	Value	Unit	USD (\$) conversion
1. ANNUAL FIXED COST	27,364.26	Php/yr	482.84
Depreciation	11,194.47	Php/yr	197.52
Interest on Investment	13,682.13	Php/yr	241.42
Tax and Insurance	2,487.66	Php/yr	43.89
2. VARIABLE COST	103.16	Php/hr	1.82
Operator's Wage	43.75	Php/hr	0.77
Repair and Maintenance	37.31	Php/hr	0.66
Power Cost	22.1	Php/hr	0.39
3. BREAKEVEN POINT	6,889	kg/yr	-

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Fig. 5. Cost curve of using the machine

3.2.5 Market Feasibility

393 Table 8 outlines the market feasibility of the machine. Based on the gathered data regarding
 394 the annual volume of collected PET bottles (60,000kg/yr), a comparative projection of
 395 income for local junkshops, with and without a shredding machine, was calculated. The
 396 assumption was made that the plastic shredder is individually owned by the local junkshop.
 397 The results revealed that utilizing the PET bottle shredder would yield an annual net income
 398 difference of Php757,174.00/yr (\$13,360.17) in comparison to local junkshops operating
 399 without a shredding machine. The payback period would be as short as 0.15 years of
 400 operation or 38 working days. However, since it takes 48 days to shred a truckload of plastic
 401 products, the realistic payback period for the machine would be after the first delivery of
 402 shredded plastics, amounting to a 270% rate of return.

403
 404 **Table 8. Market feasibility of using the machine**

Particulars	Without Shredding Machine	With Shredding Machine
a. Initial cost		124,383 (\$482.84)
b. Amount of PET to be processed, kg/yr	60,000	60,000
c. Ten-wheeler van Capacity, kg/truckload	2,450	11,359
d. Number of deliveries per year	28	6
e. Average transportation cost per trip, Php	10,000 (\$176.45)	10,000 (\$176.45)
f. Annual Transportation cost, Php/yr	280,000 (\$4,940.54)	60,000 (\$1,058.69)
g. Annual Fixed cost, Php/yr	-	27,364.26 (\$482.84)
h. Annual Variable cost, Php/yr	-	253,058.65 (\$4,465.16)
i. Annual Operating cost, Php/yr	280,000 (\$4,940.54)	280,422.91 (\$4,948.00)
j. Unshredded PET bottle plastic melting factory price, Php/kg	18 (\$0.32)	-
k. Shredded PET bottle plastic melting factory price, Php/kg	-	49.5 (\$0.87)
l. PET bottle junkshop price, Php/kg	18 (\$0.32)	18 (\$0.32)
m. Profit, Php/kg	20 (\$0.35)	31.4 (\$0.55)
n. Annual Revenue, Php/yr	1,200,000.00 (\$21173.74)	1,884,000 (\$33,242.77)
o. Annual Net Income, Php/yr	920,000.00 (\$16,233.20)	1,603,577 (\$28,294.76)
p. Additional Income (Bonus) if plant quota (4 tons) is met, Php/yr	-	73,597 (\$1,298.60)
q. Difference in Annual Net Income, Php/yr	683,577 (\$12,061.57)	
r. Payback Period, yrs.	0.15	
s. Rate of Return, %	270	

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406 **4. CONCLUSION**

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408 Based on the study's objectives and findings, the following conclusions can be drawn. The
 409 concept and mechanism of the developed PET bottle shredder machine have been proven
 410 effective in reducing labor, time, and expenses involved in processing PET bottles, while
 411 also generating additional income for collectors and consolidators. The machine can be
 412 constructed using locally available materials and local manufacturing technologies. The
 413 machine's performance was satisfactory across its key parameters, including shredding
 414 capacity and shredding efficiency. Shredding efficiency decreased as shaft speed increased;
 415 however, higher shaft speeds resulted in greater shredding capacity for the machine.
 416 The energy demand of the shredder was observed to be 0.132 kW-hr/kg at a shaft speed of
 417 50rpm and 0.205 kW-hr/kg at 30rpm. The power consumption of the machine was deemed

418 economical, with an annual power consumption cost of Php 39,005 (\$688.23). The cost
419 analysis of utilizing the machine demonstrated its financial viability. Local junkshop owners
420 could reduce their transportation costs by 21.4 percent and potentially increase profits by
421 Php 757,174 (\$13,360.17) per year by implementing the machine for shredding PET bottle
422 products. The fabrication cost of the machine was Php 124,383 (\$482.84). The projected
423 annual operating cost amounted to Php 280,423 (\$4,948.00), with a calculated breakeven
424 weight of 6,889kg/yr and a payback period of 38 working days.
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429 **DISCLAIMER**

430 Some part of this manuscript was previously presented and published in the following
431 conference.
432

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439

440 **COMPETING INTERESTS**

441

442 Authors have declared that no competing interests exist.
443

444 **AUTHORS' CONTRIBUTIONS**

445

446 This work was a collaborative effort involving all authors. Author MEC conducted the
447 interviews, designed and fabricated the machine, analyzed the data, and prepared the
448 manuscript. Authors RBG, HFG, and TBS supervised the execution of this work, contributing
449 insights to data gathering and machine evaluation. All authors thoroughly reviewed and
450 approved the final manuscript.
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