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Energy Consumption Analysis in the Plastic Waste Recycling Process: A Case Study of Amazia Vision Enterprise Private Limited, Satara, India

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Abstract: Every year, over 400 million MT of plastic are produced around the world, majority of which aren't managed properly, leading to immeasurable damage to the environment. Only 14-18% as a global average of plastic waste is recycled with only few companies take part in the plastic recycling process. The main goal of the study was to analyse the energy demand and provide a feasible technical solution to conserve energy and reduce the plant's operating costs. A plastic waste recycling station, Amazia Vision Enterprise Private Limited, Satara, India, was purposively chosen to conduct an extensive evaluation of energy requirements. An energy analysis was performed on the process to determine the potential for energy savings and cost reductions. It also aims to reduce the amount of energy used at each stage of the process. Theoretical solutions to conserve energy, reduce waste generation, and thus lower operating costs have been proposed. According to the analysis and subsequent evaluation, the energy requirement can be reduced to 8% of the initial value. A technical solution for recycling of plastics has been proposed which can be implemented to test the feasibility interms of both technical and economical parameters. An energy conservation analysis of a plant has been presented in this paper which will provide a road-map to conserve ever increasing energy consumption and drive more investors in the plastic recycling sector for best plastic waste management practices.

Keywords: *Energy conservation, Extrusion, Plastic waste, Recycling, Thermoplastics, Thermostats*

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1. Introduction

Every year, nearly 140 MT of plastics are produced globally (Business Line, 2020; The Hindu, 2020) A latest review in Western Europe estimated annual total plastic consumption at 49 MT, or 98 kg per head of population (Achilias, Roupakias, Megalokonomos, Lappas, & Antonakou, 2007). Outside of the European Union, the United States, China, India, and Eastern Europe consumed nearly 80% of the global plastics additives. Asia lacks proper source segregation, recycling and disposal system of waste (Khanal, Giri & Mainali, 2022). South East Asia, particularly India and China, has appeared as the world leader in plastics usage, with over 52 MT consumed in 2004. The yearly use of plastics in the United States is expected to be 38.9 MT, closely followed by China's annual consumption of 38.8 MT. With a total annual consumption of 12.5 MT, India is ranked as the third largest consumer market for plastics in 2009.

Plastic usage in India has increased dramatically throughout the 1990s, with an average annual growth rate of 12% (Mutha & Premnath, 2006). The current pace of growth in India's plastic use is also expected to be higher than that of China and any other emerging country. India produced 0.363 MT of plastic polymer in 1990–1991, but within a decade, an astonishing 890 percent rise led to total plastics output reaching 3.2 MT (2000–2001). In 2005–2006, India's plastics output increased to 4.77 MT, with PP and HDPE accounting for the majority (HDPE).

On average, commodity plastics such as PE, PP, PVC, and polystyrene (PS) contribute for 80% of total plastic usage in India. In India, per capita use of plastics was 0.8 kg in 1990–1991, and within a decade, per capita consumption increased considerably to 3.5 kg in 2000 (Kaushal, 2012). Plastics in MSW have also expanded dramatically, rising from 0.7 percent in 1971 to 4 percent in 1995 (NPWMTF, 1997). However, it is still significantly lower than the world average (18 kg) (Mutha & Premnath, 2006). Nevertheless, as per the National Plastic Waste Management Task Force's research results (NPWMTF, 1997), packaging accounts for 52% of total plastic use in India. In India, 1.3 MT of plastic garbage is created annually, accounting for 36% of total plastics use. In India, over 42 percent of all produced plastic trash is recycled by 20,000 recycling businesses, with a total potential of 0.37 MT/year. On other hand, as per the Central Pollution Control Board's 2019-2020 report, India recycles roughly 60% of its plastic waste (Tejaswini, Pathak, Ramkrishna, & Ganesh, 2022). According to NPWMTF (1997), more than 5,400 tonnes of plastic garbage were created in India every day in 2000–2001.

The current method of removing plastic from street litter and landfills makes it impossible to recycle 100% of plastic. The rest 40% of it ends up in landfills, littering streets, water bodies etc., and why does that happen just because it is disposed of incorrectly(P. Singh & Sharma, 2016; R. K. Singh & Ruj, 2015). 80% of the dry waste generated every day is plastic, if plastic is managed; rest is not difficult at all. India will be as clean and beautiful as any developed countries (Gopinath, Nagarajan, Krishnan, & Malolan, 2020; Ghadge, Khare, Bhosale, Giri, & Jadhav, 2021). Because of the wide spectrum of recycling and recovery processes, the terminology for plastics recycling is complicated and often unclear (Banerjee & Srivastava, 2012; Banerjee, Srivastava, & Hung, 2014; Bhattacharya, Chandrasekhar, Roy, & Khan, 2018; Hussain, Bhattacharya, & Ahmed, 2019). There are four types of plastic recycling; primary (mechanical reprocessing into a product with comparable attributes), secondary (mechanical reprocessing into goods with lesser properties), tertiary (recovery of chemical ingredients), and quaternary (recovery of chemical constituents) (recovery of energy). Primary recycling is sometimes referred to as closed-loop recycling, whereas secondary recycling is referred to as degrading. Tertiary recycling is also known as chemical recycling or feedstock recycling, and it occurs when a polymer is depolymerized to its chemical elements (Siddiqui & Pandey, 2013; Sharma & Jain, 2019; Sharma & Mallubhotla, 2019; Vanapalli, Samal, Dubey, & Bhattacharya, 2019). Energy recoveries, energy from trash, or valorisation are all examples of quaternary recycling. Composting is also an option for biodegradable plastics.

In this paper, the energy demand and potential for cost reduction in an automated plastic recycling plant in Satara, India has been investigated. A technical solution has been proposed and implemented to test the feasibility, both technically and economically. An energy conservation analysis of a plant has been presented that will be able to provide a road-map to conserve ever increasing energy consumption and drive more investors in the plastic recycling sector for best plastic waste management practices.

2. Materials and methods

The Amazia Vision Enterprise Private Limited located in Satara, Maharashtra, India was purposively chosen for this study. The concept of process tearing and partitioning was implemented in the initial stage of the study. Flow sheet was divided in suitable number of blocks. Each block was treated and solved separately. Material and energy balance and operating conditions of each blocks were evaluated to find the scope for energy conservation and cost optimization. The data from operating conditions was analyzed to properly make the choice of the design variable which could be used for further study.

All process equipment in each block were operated under a range of conditions; such as quality of plastic waste feed stocks, varying operating conditions at different production rates. The utilities used in this industry are mostly electricity and water used to run equipments and washing purpose. The rating of all electrical motors connected to various equipments as well as shafts were calculated. The revolutions per minute (rpm) of each and every impeller or shaft were measured and thus the power consumed by these equipments were calculated. The rpm of shaft or impeller were optimized at suitable power requirement. After performing the theoretical energy demand in the existing process, it was compared with actual demand. By following the methodology, and disintegrating the process into five parts, energy evaluation was made easier. The rpm of shafts and impellers were optimized by various trials conducted on each rotating equipment. This method provided a clear-cut strategy for selection of process variables, calculation and evaluation of chemical process and physical parameters.

3. Results

3.1. About Amazia Vision Enterprise Private Limited

The company's goal is to recycle plastic and produce recycled products such as High Density Polyethylene (HDPE) granules, Polypropylene (PP) granules, Low Density Polyethylene (LDPE) packaging bags, PP String, etc. (Figure 1). The company produces 600Mt/month HDPE granules, 200Mt/month PP granules, 20Mt/month LDPE packing bags and 40Mt/month PP twine capacity. The main recycled plastic here is HDPE and PP. The company covers six acres of land and has an additional two acres of non-agricultural land. The factory has been built in an area of 1.5 hectares.

The water is supplied to the industry through a well and additional water pipeline directly from the Krishna River.

The electricity supplied is 33 kV and can take a load of 3025 kVA. The factory has warehouses in Pune, Kolhapur, Shirwal and Satara. Most of the recycled scrap is picked up at these locations.

Table 1: Quantity of products recycled daily

Equipment	Name of the Equipment	Input (kg/day)	Output (kg/day)	Product
Automatic	RP1	10800	8625	HD5007
	RP2	10800	8625	WPP Natural PP
Manual	RP3	4200	2925	HD5007 and WPP
	RP4	4200	2925	Red, Blue and Green PP
	RP5	Under maintenance		

Table 2: Equipment details

S.N.	Equipment Type	Qty	Brief Description
1	Vibrators	1	A Vibratory Screen is needed to separate dust from the waste, which is to be fed on to the Sorting Conveyor. All the collected waste is loaded on to this vibrator to remove dust.
2	Feed conveyor	1	A Feed Conveyor will need to convey the waste from the vibrator to the Sorting Conveyor
3	Sorting conveyor	1	This is a slow moving Flat conveyor. The plastic/waste which can be monetized will be picked from the conveyor and will be dumped on any of the side conveyors. All the waste which is of value will be hand sorted and the rest will go to the other side for shredding.
4	Shredding conveyor	1	An input conveyor for the shredder is required to charge the shredder. The waste will fall on this conveyor from the Sorting Conveyor and will primarily fall all waste which cannot be monetized.
5	Shredder	1	Shredder with a capacity of 500 Kg/hr is required to shred the waste. The shredded waste will be further processed.
6	Discharge conveyor	1	A discharge conveyor will carry the shredded waste to one of the Bin for final removal from the Collection Facility.
7	Bins	10	Numbers of Collection Bins will be needed next to the sorting conveyors for collecting any foreign material which needs sending for land filling, dust and shredded waste.
8	Bio clave.	1	This is state-of-the-art equipment which is used if the waste coming from the Collection centers is wet. This removes all the moisture from the waste before it is transferred to the Vibrator.
9	Lumber making machine	1	Plastic Extrusion Plant & Machinery (with standard accessories) •Production: 1000 Kg/hr •Power: 817kw •Water: (80% reusable) •Human resources: 4 Skilled

There are five large machines that work continuously throughout the recycling process. It includes a 2-stage cascade extrusion line of 180mm with die head cutter from RR Plastic with a capacity of 1Mt/h, a 120mm venting extruder, a 140mm mother-baby extruder, a fully automatic washing line with a capacity of 1.5 MT from Bhavya Machinery, Umargaon brand and a color sorting machine with a capacity of 1 MT from Venus Color Sorting, Coimbatore. They also have a wastewater treatment plant (ETP) with a capacity of 1100 liters/day. The company employs around 400 experienced employees. Table 1 shows the amount of plastic processed at the factory per day

Plastic recycling process

Once the plastic regrind material is collected from various warehouses, it is first sorted (2 days) as per the plastic quality and further sent to the size reduction (1 day) process. The materials that are left out after size reduction is the die waste. Once the final plastic is collected, it is thoroughly washed, dried and goes through a complete quality check (4 days). The waste water after washing (dirty water) is to be treated in ETP and then it is discharged. Now, after washing, the plastic is sent to a compounding and extrusion machine wherein it is completely crushed, melted and takes 4 days to finish. The next process taking place in the extrusion is the dehumidification and polishing (2 days) wherein the plastic is granulated into die face cut and is polished to give a final product. The final product then goes through a quality check and later to the bagging (1 day). All the recycled plastic that passes the quality check is bagged and is dispatched (1 day) to the warehouse for further distribution to various companies. The by-product or the waste (Dubban) that is generated is further used for manufacturing PP twine and for Pyrolysis (Saxena & Srivastava, 2022). This process takes 15 days to complete (Figure 1).

Types of plastic waste collected

Two different types of plastic wastes are collected
Recyclable Plastics (Thermoplastics): PET, HDPE, LDPE, PP, PVC, PS, etc.
Non-Recyclable Plastics (Thermoset & others): Multilayer & Laminated Plastics, PUF, Bakelite, Polycarbonate, Nylon, etc. There are seven categories of plastics, like PET, HDPE, PVC, LDPE, PP, PS and other. The typical thermoplastic and thermosetting resins are shown in Table 3.

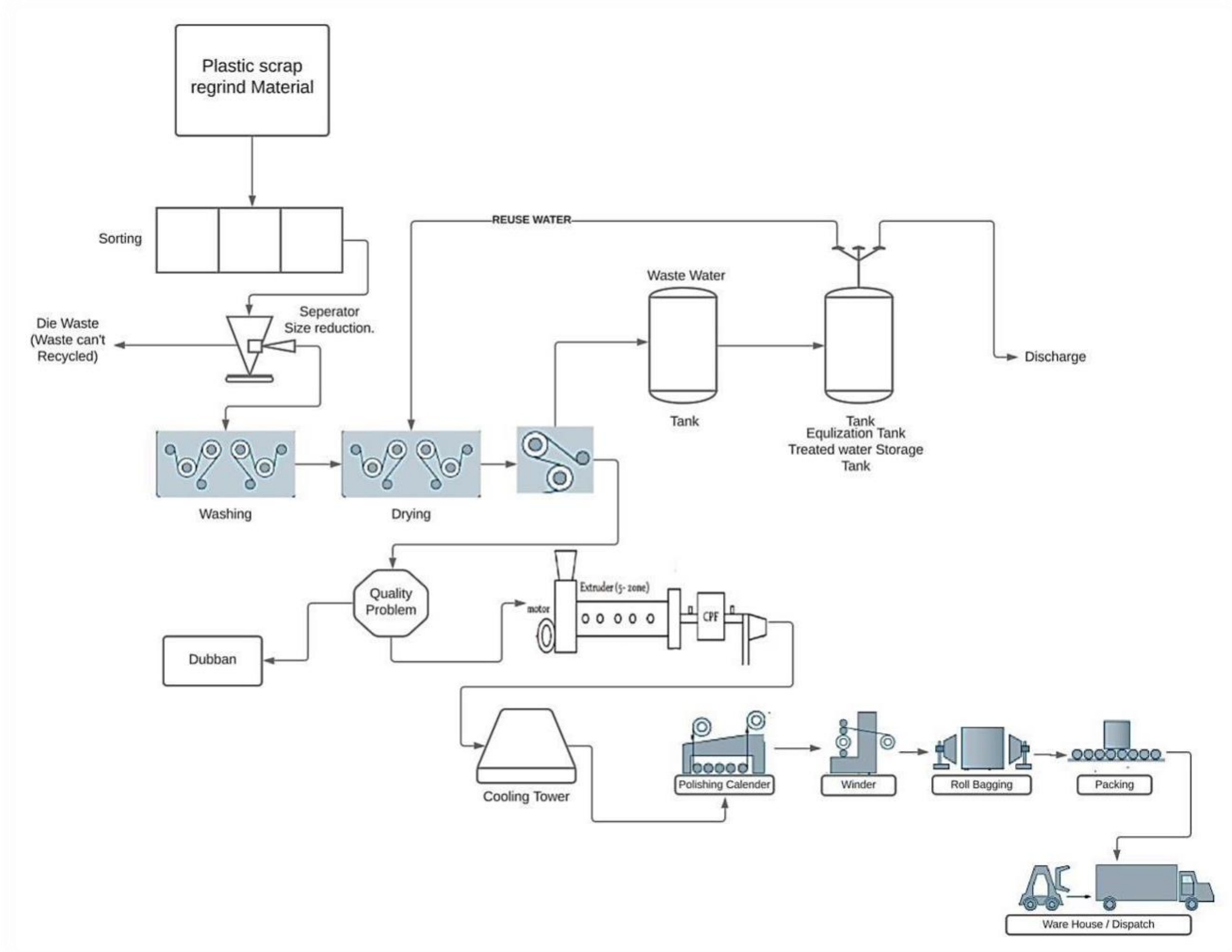

Figure 1: Process flow diagram of plastic recycle process

Table 3: Thermoplastic and thermosetting resins

Thermo plastic	Thermoset Plastic
1 Polyethylene Terephthalate (PET)	1 Bakelite
2 Polypropylene (PP)	2 Epoxy
3 Poly Vinyl Acetate (PVA)	3 Melamine
4 Poly Vinyl Chloride (PVC)	4 Polyester
5 Polystyrene	5 Polyurethane
6 Low Density Polyethylene (LDPE)	6 Urea-Formaldehyde
7 High Density Polyethylene (HDPE)	

4. Discussion

The methods of tearing and partitioning lead us to study the process better when implemented (Smith, 1995; Biegler, Grossmann, & Westerberg, 1997). Dividing the process flow sheet into several parts or number of blocks give a more efficient data to work on, considering the partitioning created needs to be treated and solved separately. The operating conditions data and mechanical design of the equipment must be analyzed properly to make the choice of the design variable used for the study. It is necessary that each part of the process is operated under a range of conditions, such as quality of waste feed stocks, varying operating conditions, and different production rates (Satapathy, 2017; Letcher, 2020; Ncube, Ude, Ogunmuyiwa, Zulkifli, & Beas, 2021). Since all the equipment's involved and operating are electrical utilities and the rest is water for washing purpose, it is found out to be having a different rating for all electrical motors connected as well as shafts. Further, the RPM of each shaft and equipment was measured and, using specific equations and methods, the energy consumed was calculated. The date for the energy consumed by each machine and the factors involved has been presented in Table 4. Similarly, the RPM data was also calculated, considering the power utilized and originally required. The RPM data has been presented in Table 5.

The Table 4 shows the energy consumed by every machine that is involved in the process; the data is represented on a kWh/day and kWh/month basis. Considering the total HP of every machine, initially, the power was calculated and then the total energy consumed.

According to the methods and equations used, the data accumulated was more than expected. Considering the aim, the cost of the total recycling process needs to be optimized and, less consumption of electricity is necessary. If the optimum conditions selected, the process for the design is not certainly the most optimum, resulting it being inefficient. It is a job to understand the process and identify the issue and make changes that are efficient after creating optimum conditions. This will only be possible by studying and analysing each partitioned block deep enough, making sure that change does not affect the efficiency. By working towards the aim and never losing sight of the goal to optimize, the cost and maximizing the profit of a business is crucial. Hopefully, this discussion will provide a logical method for selection of process variables, calculations and evolution of chemical process optimization. It is also recommended to carry out the rigorous analysis of all manipulated design variables to arrive at the optimal cost, which comprises capital and the operational cost.

The decrease in energy need was determined by following the approach from the previous section. Table 6 illustrates the actual energy consumption in a plant each month and the reduction in energy demand after applying the trial in plant based on recommendations in methodology. One ton of recycled plastic, in theory, saves 5,774 Kwh of energy, 16.3 barrels of oil, 98 million BTUs of energy, and 30 cubic yards of landfill space. Table 6 shows that there was 8% decrease in energy usage for the same process but with optimized parameters. It is recommended to carry out detailed evaluation of dominant physical parameters like revolutions per minute and power factor at each stage of the process.

Table 4: Energy consumed per machine

No.	Machine Type	Total HP	Power(w)	Energy consumption (kWh/day)/(Month)	
				Day	**Month**
1	Washing m/c no. 1	355.5	265096.3	6362.31	190869.1
2	Washing m/c no. 2	137.5	102533.73	2460.81	73824.3
3	Washing m/c no. 3	59	43996.29	1055.91	31677.3
4	Washing m/c no. 4	104	77552.78	1861.27	55832.2
5	RP 1 Main m/c	458	341530.54	8196.73	245902
6	RP 2 Main m/c	125	93212.848	2237.1	67113
7	RP 3 Main m/c	125	93212.848	2237.1	67113
8	RP 4 Main m/c	45	35556.49	805.356	24160.7
9	Eglo no.1	100	74569.987	1786.95	53690.4
10	E m/c no.2 (SD)	45.5	33929.34	814.304	24429.1
11	E m/c no.2 (LMP)	40	29827.99	715.872	21476.2
12	E m/c no.2 (GM/C)	27	20133.89	483.312	14496.4
13	Eglo no.3	7	5219.89	125.277	3758.32
14	Tubing m/c no.1	40.5	30200.84	724.82	21744.6
15	Cutter m/c no.1	5	3728.499	89.484	2684.52
16	Cutter m/c no.2	5	3728.499	89.484	2684.52
17	ETP Plant	7	5219.89	125.277	3758.32

Table 5: Various parameters calculated

Machine	Power supply frequency (Hz)	Total power Utilized (kW)	Number of Pole	RPM of machine (rpm)	Torque (N-m)
RP1 (AUTO)	50	817	4	1500	5201.18
RP2(AUTO)	50	817	4	1500	5201.18
RP3(MAN)	50	410	6	1000	3915.21
RP4(MAN)	50	410	6	1000	3915.21
RP5(MAN)	Under Maintenance				

Table 6: Energy consumption

No.	Machine Type	Energy consumption at actual (kWh/day)/(Month)	Energy consumption (kWh/day)/(Month)
1	Washing m/c no. 1	190869.1	175599.57
2	Washing m/c no. 2	73824.3	67918.35
3	Washing m/c no. 3	31677.3	29143.11
4	Washing m/c no. 4	55832.2	51365.62
5	RP 1 Main m/c	245902	226229.84
6	RP 2 Main m/c	67113	61743.96
7	RP 3 Main m/c	67113	61743.96
8	RP 4 Main m/c	24160.7	22227.84
9	Eglo no.1	53690.4	49395.16
10	E m/c no.2 (SD)	24429.1	22474.72
11	E m/c no.2 (LMP)	21476.2	19758.10
12	E m/c no.2 (GM/C)	14496.4	13336.68
13	Eglo no.3	3758.32	3457.65
14	Tubing m/c no.1	21744.6	20005.03
15	Cutter m/c no.1	2684.52	2469.75
16	Cutter m/c no.2	2684.52	2469.75
17	ETP Plant	3758.32	3457.65
		Σ= 905213.98	Σ= 832796.74

5. Conclusion

The current work identified that there is great potential for energy conservation in Amazia Vision Enterprise Private Limited, Satara. It was found that there is potential of immediate reduction of energy requirements by 8% of the actual value. It is recommended that optimization can be performed for various process parameters at each stage of the process. In order to meet the targets for energy savings and cost optimization, a detailed study of economics over the process is also recommended.

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