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Assessment of polymer recycling and the quality of recycled products in Khartoum state

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***Abstract:** In spite of the great popularity and wide application of plastic products due to their attractive properties and ease of processing, economical costs, a challenge of managing plastic waste is continuously growing. Recycling emerged as one of attractive solutions to this issue. In this research paper recycling activities in Khartoum state were investigated beside the economical and environmental impact. Tensile properties were determined for some recycled plastic products. Results show that recycling has a good economical and environmental impact. Quality of recycled products can be enhanced by improving collection, sorting processes.*

I. INTRODUCTION

Polymers constitute 8% by weight and about 18% by volume of all materials going to land fill in the world [1]. Of this stream plastic packaging material constitute 40%[1]. This is due to its high visibility, voluminous nature, and slow biodegradability. Growing awareness among many communities and reduction in available landfills prompted recycling programs in most developing countries.

A. Classification of Recycling Technologies

According to the type of products obtained from recycling process, and the economical value recovered the following classification of recycling techniques can be made:

Primary recycling: which is defined as reprocessing of plastic waste into same or similar product from which it has been generated. It is used when plastic waste is uniform and uncontaminated [2]. Plastic waste can be processed alone or mixed with virgin raw material. Only thermoplastic can be recycled by this technique.

The main problems encountered in primary recycling are degradation of material resulting in loss of properties such as appearance mechanical strength chemical resistance.

Secondary recycling: The processing of plastic waste into plastic products with less demanding performance characteristics [3]. This include reprocessing based on melt homogenization using special equipment, use ground waste as filler, separation into single homogenous fractions for further processing, blending with other thermoplastic using suitable compatiblizer [2].

Tertiary recycling: recovery of chemicals from plastic waste. Polymers are thermally cracked to recover monomers, petrochemicals, and fuels.

Quaternary recycling: Recovery of energy from plastic waste. In most cases plastics are burned in specially designed incinerators to recover energy content of plastics.

Recycling Operations: Recycling techniques depend on the components of the plastic waste and the contamination level, however certain operations are necessary to improve the performance properties and facilitate process ability. The following operations are carried out before manufacturing plastic item:

Collection:

Plastic waste should be collected properly, it must be separated from non plastic wastes(papers, metals, stones, wood,…etc).Recycling codes are useful tools for further separation of plastic waste to more homogenous components and facilitate sorting.

Sorting:

This is a fundamental operation because of its strong impact on the quality, and rheological properties of the feed stock. As an example PVC and PET when processed they can experience quality defects due to rheological and incompatibility of these two resins [2]. There are many sorting methods employed in plastic waste and selection depends on the properties of the plastic waste and degree of separation required.

These methods involve manual sorting, density based sorting methods, optical sorting methods, advanced spectroscopic sorting methods.

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Table 1 densities of common thermoplastics [2]

Plastic	Density g/cm3
Poly propylene	0.9
Low density poly ethylene	0.9
High density poly ethylene	0.95
Poly styrene	1.05
Poly amide(PA6,PA66)	1.15
Poly vinyl chloride	1.4
Poly ethylene terepthalate	1.4

B. Size Reduction Operations

These operations are necessary to convert waste plastic to a form that is appropriate for convenient transport, metering, and feeding into downstream recycling process. It can be classified into the following

i) Cutting techniques (including shredders, granulators, and rotary grinders)

ii)Densification processes(such as agglomeration, compacting)

iii)Pulverization such as (disc pulverizers, turbo mills, crynogenic pulverizers).

C. Washing

Washing is required to remove any dirt and residues adhering to the plastic waste. It increases the purity of plastic, and in some cases improves the efficiency of other processes such as sorting. Washing also removes labels and water soluble glue residues [4]. Washing is accomplished by caustic soda solution or liquid soap and foreign matters. Once material is washed it need to be dried .Large fans or hovers can be used to dry plastic flakes.

D. Agglomeration

This process is carried out after material is sorted into fairly homogenous stream. The aim of agglomeration is to increase the bulk density of the waste which is necessary to ensure good feeding unit. It finds most application in waste plastics of film flakes which have bulk density of 100 to 150 kg/m3[4]. Pressing or fusion are used to achieve agglomeration of light flakes, however when thermal agglomeration is applied surface particles should be heated for relatively short time. Agglomeration is necessary for recycling feedstock of plastic bags of low density and high density polyethylene.

E. Manufacturing and Processing Techniques

Manufacturing techniques of plastic waste are similar to those of virgin plastics resins especially for homogenous waste stream, however for heterogeneous mixed plastic waste specialized reprocessing techniques may be applied. The following techniques are employed in processing waste plastics.

Extrusion: This is a continuous process for production of components such as pipes, or sheets. It can be also used to produce plastic pellets from plastic waste of more homogeneity and purity. Feed stock may be in the form of powder, pellets, and flakes [5]. It enters extruder in molten state [5] Extruders can be divided to two types single screw and twin screw extruder.

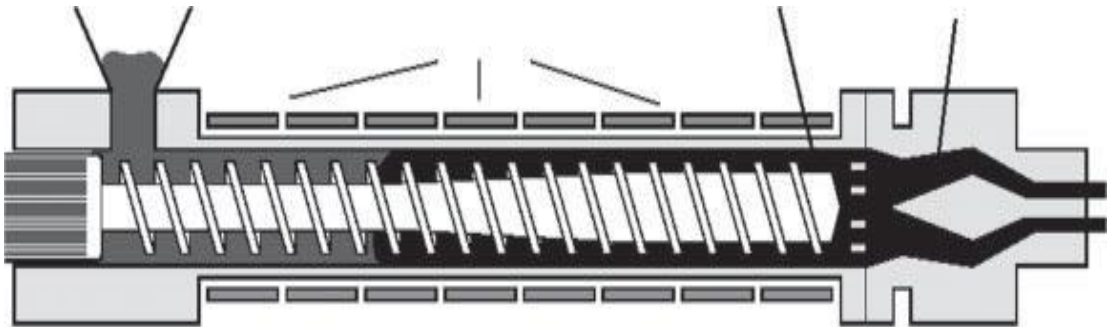

Fig 1 single extruder structure Source: [6]

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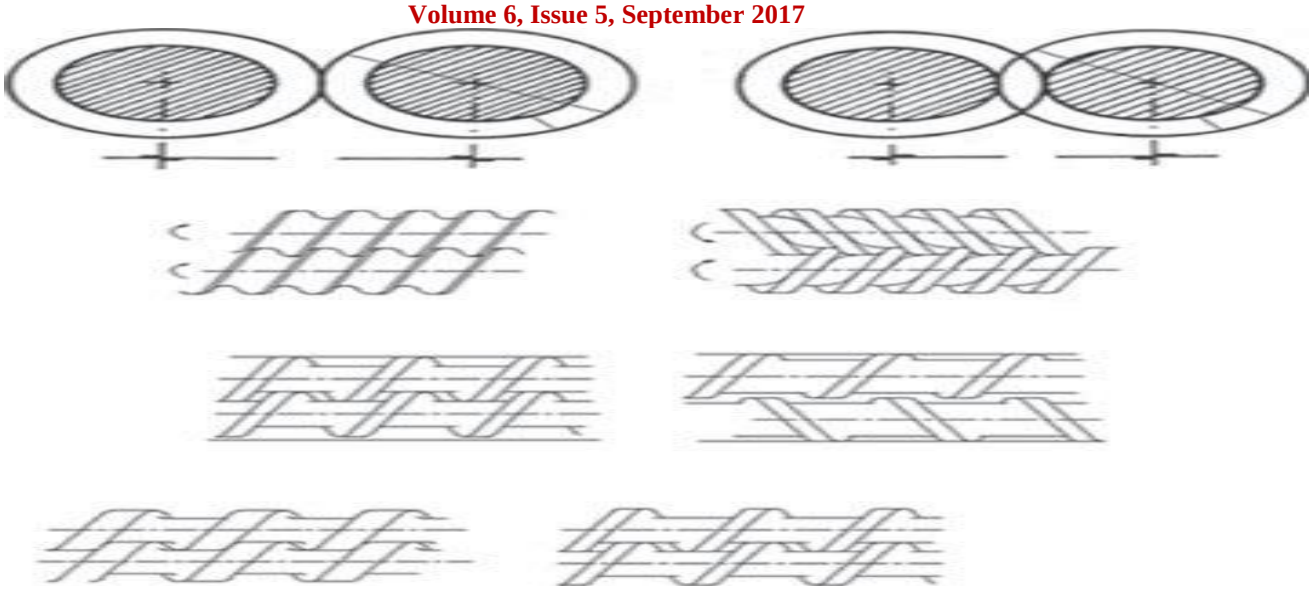

Fig .2 twin screw extruder Source: [6]

Screw characterization is determined by the ratio between the length and diameter of the screw (L/D). a common screw length is 25D[4].

Injection molding

This is one of the most common manufacturing processes in use today. It is a highly versatile process because it can be employed to manufacture both small and large components. An injection machine consist 4 components: injection unit, control system, drive system, and clamping unit [7]. Other molding processes are available like blow molding which is used produce hollow articles, compression molding which is used to manufacture both thermoplastic and thermo set products.

II. MATERIALS & METHODS

Data of this research were collected by direct interview with some of technicians and labors working in plastic waste collection, sorting, and processing, questionnaire distribution, observations, and visits to some plastic factories Samples of plastic waste feed stock, and products withdrawn and analyzed to determine their processabilty, homogeneity, and quality.

A. Study Area basic information

Khartoum state national capital of Sudan is composed of three cities Khartoum, Khartoum Bahri, Omdurman with total area of 22000km2, and population of 8,000,000. It is composed of seven localities. Most of the economical , industrial, education, health services are established in the state. Most of plastic factories are located in the state (table no 2).

B. Assessment of Plastic Recycling in Khartoum State

According to the statistics of Khartoum State, annual generated solid waste is estimated to be about 1,600,000 tons. This represents 20% of the total amount generated in Sudan. Plastic waste generated annually is 132,112tons [8] which constitute 12.1% of the total solid waste. Most of plastic waste is dumped or incinerated, and little quantity is recycled. Despite the importance of recycling, and source segregation activities yet they are made in a traditional method by the informal sector of scavengers. They do 80% of recycling activity in Khartoum State. Thus, it is obvious that this type of activity has a significant environmental and economical impact which is required to be proved in this research paper. Recyclable items and prices are subject to the composition and percentage of each item in disposed waste plays a major role in the quantity of recyclable items in addition to the geographical area, and type of activity and economic condition of the area market demand mechanism. According to the market demand, Plastic is divided into three categories:-

a) PET bottles: the consumption of this resin increased greatly and estimated to be 60000 tons per year[9]. This because of large demand of healthy water plants.

b) Soft plastic: This is the type of plastic used for packing.

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C) Injection plastics: This is the type of plastic which is collected from old plastic tubes, buckets appliances .Collection of plastic waste in residential area is achieved by trucks which transfer solid waste to intermediate stations for sorting, or direct to dumping sides. They collect 400-500 kg/day depending on the vehicle They may generate 500 SDG/ day for the group to be divided among them in an average of 100 SDG/ day type and the area. This type constitutes 40% of recyclables.

Labourers working in these trucks carry out manual sorting during the loading, and collect valuable plastic waste and other solid wastes, and sell them to their benefits. Collection of plastic waste in residential areas also accomplished by walking scavengers having a camp in the area or they may have a cart introduced by supplier This is almost composed of 4-5 scavengers collecting almost PET bottles. They start to collect and store about one ton of plastic in a week. Transfer or intermediate stations and landfills constitute a major source for recyclable collection due to the fact that there is a large amount of waste transferred daily to these areas (approximately 2500 ton/day); there are many camps for collection in these They collect about1.75 ton plastic/weak.

Table 2 : Plastic plants in Khartoum State Source: [10]

No	Types of plants	Total No of plants	Designed production capacity tons/ year	Actual production capacity tons/year	Production units	Labours
1	Robes	26	45000	23000	50000000 parcel	1500
2	Plastic sacks big(50,25kg)	7	13244	6244	62440000	500
3	Pipes	8	90000	40000	12000000 pipe	871
4	Containers	16	100000	25000	100000000	1500
5	House hold items	20	75000	18000	120000000	1500
6	Gallons(18,9,4.5 litres)	10	50000	12500	30000000	700
7	Furniture	10	20000	12500	10000000	700
8	Hoses	10	175000	5000	5000	249
9	Plastic sacks small, transparent	30	200000	100000	100000	1500
10	Cables	3	5000	250	250	40
11	Rugs	4	5000	1250	1250	40
12	Cold water reservoir	6	500	125	125	35
13	Water tanks	5	1000	250	250	30
	Total	155	779744	125919		9165

C. Experimental Work

Tests for recycling products were carried out according American society for Testing and Materials (ASTM) methods. The following tests were done:

Determination of Melt Flow Rate (MFI)

19 samples of recycling feed stock are withdrawn from different locations in Khartoum state and analyzed to investigate homogeneity and process ability. This is determined by measuring melt flow index (MFI).Test is carried out according to standard ASTM D1238-10 (Standard Method for Melt Flow Rates by Extrusion Plastometer). Test principle is based on determination of the rate of extrusion of molten thermoplastic resins using an extrusion plastometer. After specified preheating time, resin is extruded through a die with specified length and orifice diameter under prescribed conditions of temperature, load , and piston position in the barrel . Four procedures can be applied[11]

i) Procedure A it is based on measurement of mass of material that extrudes from the die in a given period. It is used for materials having melt flow rates between 0.15 and 50g/10 min.
Units used in this method is grams of material/ 10 minutes. Samples withdrawn are tested according to this method. Results are shown in table (4).
ii) Procedure B automatically time measurements used to determine melt flow rate (MFR) as well as melt flow volume (MVR).units used are g/10min,and cm3/10min.

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i) Procedure C automatically time measurement of polyolefin materials having melt flow rate greater than 75g/10min.

ii) Procedure D is multi –weight test commonly referred to as flow rate ratio (FRR). Determination is to be made using two or three different test loads.
According to procedure A temperature and load choosed according to table (3), extrusion plastometer inspected for cleanliness, sample between 2.5-8 g was weighed. The test started by initiating the timing device. Result was recorded.

Fig 3 samples of plastic waste feed stocks withdrawn from Omdurman Area

Table 3 Test conditions for select materials Source ASTMD D1238-10

Material	Temperature	Wieghts
Acetals(copolymer and homoploymer)	190	1.05/2.16
Acrylics	230	1.2/3.8
Nylons	235	1.0/2.16/21.6
Polyethylene	190	0.325/2.16/5/10/21.6
Polycarbonate	300	21.6/31.6
Polypropylene	230	2.16
Polystyrene	200	1.2/3.8
Poly vinyl choride	190	5.0/21.6

Determination of Tensile properties

This is one the most important mechanical tests. It provides indication to ability of plastic material to withstand forces pulling it apart. The test was carried out according to (ISO 527, ASTMD632-02a)

Significance: The test method is designed to produce tensile property data for control and specifications of plastic material. These properties may provide useful data for plastic engineering design purposes [12].

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Apparatus:

1- Testing machine of constant rate of cross head movement , and contains : fixed and movable member, grips holding the test specimen, drive mechanism, load indicator, extension indicator
2- Micrometer for measuring width and thickness of specimen.
Test specimen were prepared according instructions of test method (ASTMD638-2a)

Procedure

The width and thickness specimen were determined by suitable micrometer, and the specimen was placed in the grips of testing machine, the grips were tightened, the machine was operated to test 10 sample of plastic insulating pipes, tensile strength and elongation results was obtained and recorded (Table 5)

III. RESULTS & DISCUSSIONS

Table 4: Melt flow index and density results for 19 samples of recycled plastic feed stock from Omdurman-Khartoum State

No	Feed stock composition	Source	Density g/cm3	MFI(g/10min)
1	Crushed PP,PP pellets, PE flakes	Omdurman	0.75	8.83
2	Crushed HDPE	Omdurman	0.98	3.05
3	Crushed LDPE	Omdurman	0.85	6.79
4	PP flakes	Omdurman	0.83	12.67
5	PE crushed sacks	Omdurman	0.5	9.24
6	Recycled PP	Omdurman	0.82	6.5
7	Crushed PP, PP pellets	Omdurman	0.8	7.28
8	Recycled LDPE, filler	Omdurman	0.99	1.19
9	Crushed PP, PE,Others	Omdurman	1.10	13.83
10	Crushed PP, LDPE waste	Omdurman	0.67	6.22
11	Recycled PP	Omdurman	0.77	16.03
12	Recycled PP	Omdurman	0.7	9.05
13	Crushed PE	Omdurman	0.89	9.14
14	Crushed PP	Omdurman	0.69	17.69
15	Crushed PE	Omdurman	0.88	20.20
16	Crushed PP	Omdurman	0.81	9.97
17	Recycled PP	Omdurman	0.75	10.53
18	Recycled PP	Omdurman	0.84	13.6
19	Crushed PP	Omdurman	0.78	21.10

Table 5 Results of Tensile properties for recycled plastic products (electric insulation pipes)

No	Type of recycled product	Source	Feedstock composition	Length (cm)	Thickness	Tensile strength kgf	Elongation^{mm}
1	Electric insulation pipes	Twheed plant Omdurman	Mixed feed stock(PP,PE,PVC)	108	0.77	15.18	6.2
2	Electric insulation pipes	Omdurman common market	Mixed feed stock(PP,PE)	107	0.44	11.23	3.8
3	Electric insulation pipes	Gebellabi Workshop Omdurman	PP waste(crushed car batteries)	232	0.5	9.53	8.2
4	Electric insulation pipes	Gebellabi Workshop Omdurman	PP waste (colored crushed car batteries	209	0.44	10.56	8.6
5	Electric insulation pipes	Sief Eldien Workshop Omdurman	PP waste injection PP products	253	0.79	16.78	8.8
6	Electric insulation pipes	Sief Eldien Workshop Omdurman	PP waste (crushed car batteries)	251	0.86	18.32	10
7	Electric insulation	Sief Eldien	PP waste crushed	199.6	0.76	11.37	13

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	pipes	Workshop Omdurman	mixed with PE waste				
8	Electric insulation pipes	Omdurman common market	PP waste crushed waste	250.6	0.75	13.56	7.5
9	Electric insulation pipes	Jamal Workshop Omdurman	PP pellets mixed with other polyoefins	210.6	0.46	12.56	3.8
10	Electric insulation pipes	Alphanaa plastic factory Omdurman	PP pellets	271	1.33	16.68	10

1- Sudan imports large quantities of plastic resins to satisfy the great demand in plastic industry which is growing continuously, because of the need of package materials to many products. Recycling can participate in lowering quantities imported by 20% if it managed properly. Only primary recycling is practiced in Khartoum state, investment in the other recycling types will have a good impact on the national economy.

2-Results from table (4) show wide variation in MFI which is mainly due non homogeneity of the feed stock, and existence of many impurities. Sorting in most factories and workshops is carried out manually, there is no washing process in many workshops however some workshops and factories have proper manual sorting and washing which results in feed stocks of acceptable MFI.

3- Most of recycling activities focus on PP, PE, PVC waste no recycling activities are found for PET. Large quantities are disposed and dumped. Part of PET is collected crushed and exported as raw material.
4- Tensile properties of some recycled product varied greatly as shown in table 5. Feed stock composition and types of additives influence mechanical properties. Best results were obtained for plastic waste composed of car battery cases which is mainly PP feed stock.

IV. CONCLUSION AND RECOMMENDATIONS

Plastic recycling in Khartoum state have a great economical and environmental impact by reducing quantities of solid waste disposed, preservation of the environment, and lowering quantities imported of raw plastics.
1-Low MFI results of some samples withdrawn and analyzed indicates non homogeneity ,and difficulties in processing. This problem can be solved by improving sorting and collection processes.

2-It is necessary to establish quality standards for recycled plastic products and quality manuals to improve the quality and eliminate customer suspects in recycled products.

Recommendations

1-Effective and efficient management of plastic waste including application of 3R (reduce, reuse, recycle) is essential. Raise of awareness among the community about hazardous and environmental impacts of plastic waste, beside involvement and cooperation of families, and non government organizations (NGOs) in collection process of plastic waste.
2-Improvement of collection, sorting, and transportation of plastic waste. Recycling code should be imposed to all plastic products to facilitate waste sorting process. Solid waste collection bins of all sizes must be provided to all families, cafeterias, schools, and streets to capture plastic wastes.

3-Appllication of advanced technology in recycling activities is necessary beside encouragement of investment in pyrolysis, tertiary and quaternary plastic recycling to produce chemicals , fuels, and energy from mixed waste'. Quality standards of recycled plastic products should be prepared , beside quality manual for optimum collection, sorting, processes, and adequate additives to enhance the quality of recycled products.

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