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UNIDO'S INNOVATIVE APPROACH FOR UTILIZATION OF PLASTIC WASTE FROM THE INDIAN PAPER INDUSTRY AS RESOURCE UNDER CIRCULAR ECONOMY FRAMEWORK

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Abstract:

Disposal of the plastic wastes generated Indian paper mills poses severe challenge for the paper industry from an environmental point of view. Disposal also represents a loss of resources with potential alternative, albeit unexplored applications. While co-processing of such plastic wastes in cement plants has emerged as an option still has limitations due to combination of technical, economic and logistical factors.

United nations Industrial Development Organisations (UNIDO) has been working on the development of a potential solution for the utilization of plastic wastes generated in recycled-fibre-based paper mills. The innovative approach involves thermo-chemical conversion of the mixed plastic waste under controlled process conditions resulting in generation of oil, and syn gas finding application as source of energy and Char as value added product in rubber compounding in rubber industry.

The present article highlights the findings of the pilot scale studies carried out based on the plastic waste used from one of the paper mills from Muzaffarnagar paper cluster to share the technical feasibility of the developed innovative thermos chemical treatment process which could provide a sustainable solution for the utilization of plastic wastes generated in recycled fibre-based paper mill.

Keywords: Thermochemical treatment, Char, Syn gas, Bio oil, Carbon Black

Introduction

The trend towards sustainability in the pulp and paper industry envisages wastepaper recycling and recycled wastepaper (RCF) has emerged as one of the major raw materials for paper and board production in India which contribute to around 73% of the total production of paper, boards and newsprint. About 85% paper mills in India use wastepaper as primary fibre source for paper, paperboard, and newsprint production producing more 15 million tons of paper and paperboard from the recycled waste paper-based segment of paper industry. As a result, huge quantities of plastic waste (more than 0.5 million tons) is generated annually posing one of the serious challenge in disposal of residual plastic generated at the mills.

The Indian paper industry is highly fragmented consisting mainly small and medium size paper mills located across the country. Majority of the paper mills exist in clusters located mainly in

Gujrat, Tamil Nadu, Uttar Pradesh, Maharashtra, and Punjab and these paper clusters contributes to around 50% of the total paper and boards production. Legal, statutory, and social issues encountered by the paper mill in disposal of plastic waste have a direct impact on the production and profitability. Government rules "Plastic Waste Management Rules, 2016" further tightens the role of plastic waste generating companies in mitigating it too. Though co-processing of the plastic waste generated in paper mills in cement plants has been adopted as an option to fulfil the regulatory requirement, this remains as a challenge in respect to techno economic consideration besides loss of valuable resources. Plastic waste generated does not have any defined characteristics.

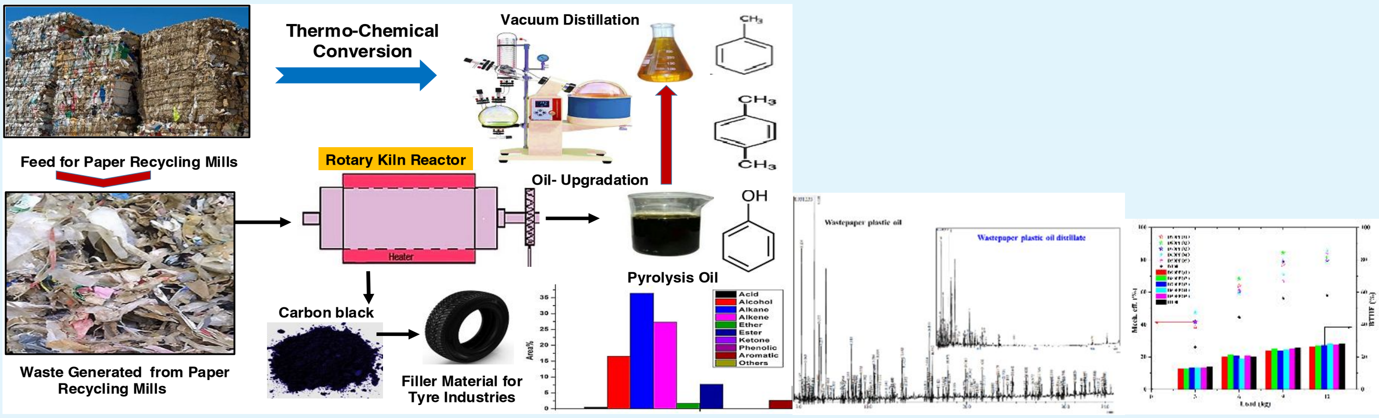
This issue was also highlighted as part of a diagnostic assessment of the Indian pulp and paper industry, conducted by the United Nations Industrial Development Organization (UNIDO) in 2017. The assessment was conducted under a project titled 'Development and adoption of appropriate technologies for enhancing productivity in the pulp and paper sector' (2015-2018), supported by the Department for Promotion of Industry and Internal Trade (DPIIT), Government of India. Highlighting the importance of a circular economy approach, the assessment highlighted that it was important for incoming raw material (waste paper) to be sorted for removal of plastic as much as possible at source i.e. collection site (thereby avoiding the generation of excessive plastic waste at the paper mill site and also improving process efficiency and product quality), but also exploring methods for the utilization/ recycling of such plastic waste segregated at source or at the paper mill site as input to allied industries (UNIDO, 2018).

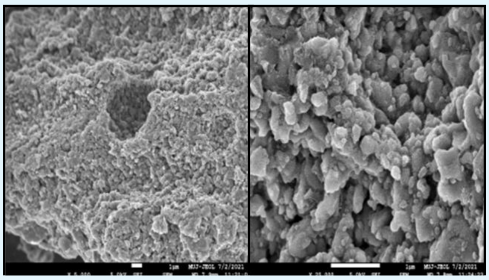
Innovative Treatment Approach - Thermo-chemical treatment process:

Conventionally, incinerating plastic waste was preferred technique for disposal of paper plastic waste but due to the toxic gases and chemicals released, the practice is put to a halt. Also direct burning of the plastic waste is barrier to circular economy. Thermo chemical treatment under controlled environment and conversion is suggested technology for resources recovery. It reduces waste going to landfill and greenhouse gas emissions. Thus, an immediate solution, and one of the emerging ways to get rid of this plastic waste could be the thermo chemical treatment process under controlled environment and conversion of plastic waste into value added product is getting popularity.

Thermo-chemical conversion of paper plastic waste has been carried out, and the products are upgraded and utilized for different applications. The process flow and high-level results are discussed below and given in Figure 1.

Figure 1 Overall Process including feedstock conversion and product upgradation





Sr. No.	Properties tested	Test Method	STD	Char
i)	Hardness (Shore A)	ASTM D2240	63/64	58
ii)	Modulus at 100% (Kg/sq.cm)		23	12
iii)	Modulus at 200% (Kg/sq.cm)	ASTM	61	15
vi)	Modulus at 300% (Kg/sq.cm)	D412	113	18
v)	Tensile Strength (Kg/sq.cm)		123	18
vi)	Elongation at break(%)		320	322
vii)	Tear Strength (kg/cm)	ASTM D624	66	15

Materials and Methods

In this study, feed was industrial paper plastic procured from a paper mill in Uttar Pradesh. The heterogenous feed contains pure plastic, mix plastic with aluminium, pure aluminium, Paper, Cloths, and others. The composition of feedstock is summarized in Figure 2 and Table 1.

Figure 2: Feed composition

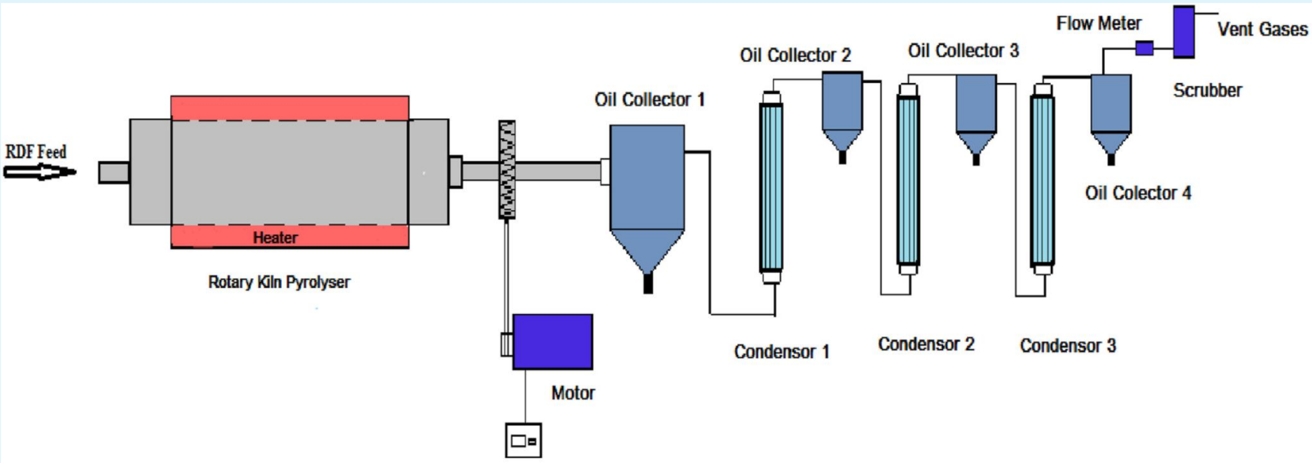
Table 1: Feedstock components

BATCH	PURE PLASTIC (gm)	MIX (PLASTIC & ALUMINIUM) (gm)	PURE ALUMINIUM (gm)	PAPER (gm)	CLOTHS (gm)	OTHERS (gm)	TOTAL (gm)
1	357	459	40	98	14	32	1000
2	403	368	66	120	19	24	1000
3	361	433	59	104	12	31	1000
Average (gm)	373.6	420	55	107.3	15	29.1	1000
%	37.36	42	5.50	10.73	1.50	2.91	100

Experimental Section

Experiments were carried out in rotary kiln reactor with 3-5 kg feed sample that was initially preheated for 1 h at 150 °C for moisture removal. Further, the temperature was increased up to 500-700 °C at 20 °C /min for 180 min with a rotary speed of 1 round per minute. Oil fractions were collected separately from the first condenser vessels (V1) that are analyzed for its composition and petrochemical properties. The aqueous and oil phases of the liquid product were separated and weighed, whereas char was extracted from the rotary drum once the room temperature was achieved inside the rotary kiln by natural cooling. The amounts of oil and char obtained was measured and the gas yield was calculated by difference. The equipment details are given in Figure 3.

Figure 3: Schematic of rotary kiln thermo chemical treatment unit



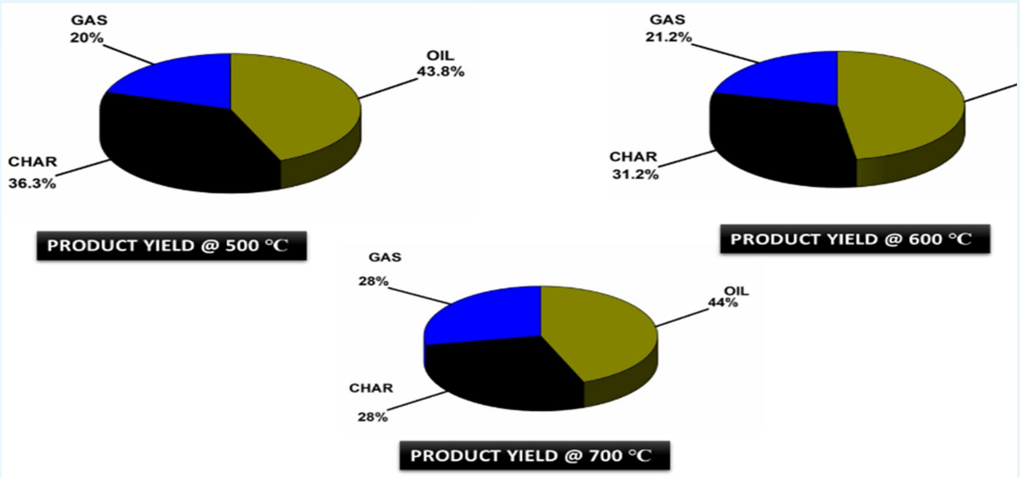
Characterization techniques

Bio-oil fractions were analyzed using a Gas chromatograph Mass Spectrometry (GC-MS) analyzer (Shimadzu, Model: QP2020) to quantify their chemical contents.

Results and Discussion

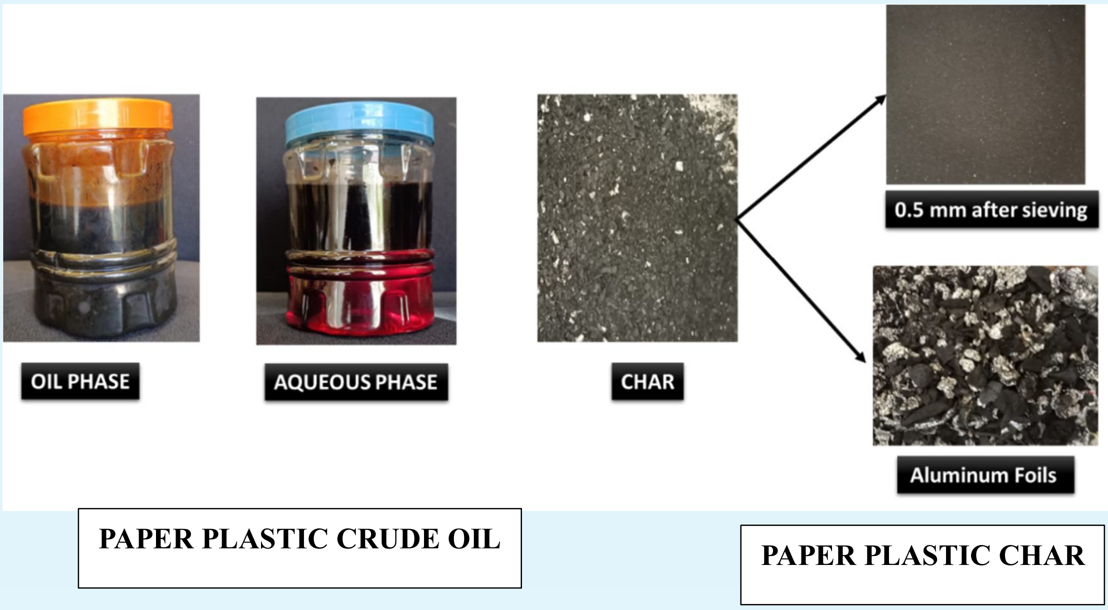
The current study mainly focuses on the thermo chemical treatment of paper plastic waste in a rotary kiln reactor. Thermo chemical treatment was carried out in the temperature range of 500 °C -700 °C and the product yield distribution was shown in the Figure 4.

Figure 4: Product yield distribution at different temperature conditions



From the above results, it was observed that maximum oil yield (47.6%) obtained at 600 ^{0}C and char yield (36%) at 500^{0}C. The products obtained from optimum conditions were analysed for commercial applications.

Figure 5 Physical state of paper plastic crude oil and char



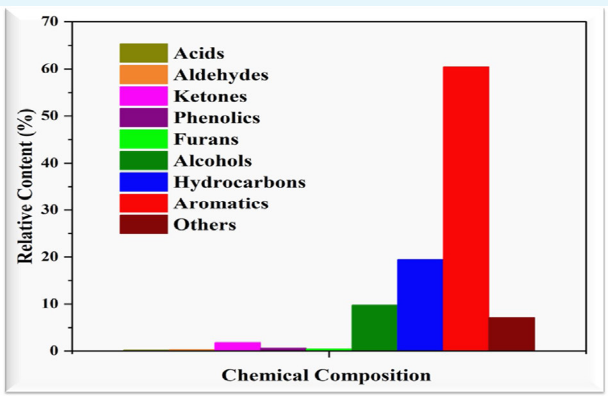
Oil Characterization: The oil was analyzed for petrochemical properties, and it was shown in the Table 2. The oil quality is near to the diesel grade fuel, however, it needs to be upgraded for commercial applications.

Table 2: Paper plastic oil characterization

SI.NO	Test Parameters	Unit	Limit (IS 1460:2017)	Results	Test Method
1	Gross Calorific Value (GCV)	K.cal/Kg	11000	7141.4	IS 1448 (Part 7)
2	Total Acid Number (TAN)	Mg of KOH/g	Max 0.20	28.44	IS 1448 (Part 2)
3	Flash Point	°C	Min. 15	<25	IS 1448 (Part 21)
4	Pour Point	°C	Max.15	-6.9	IS 1448 (Part 10)
5	Kinematic Viscosity	cSt.	2.0 to 4.5	5.09	IS 1448 (Part 25)
6	Total organic Carbon	%	Not specified	57.82	JL/CS/STP/89
7	Fire Point	°C		64	

The GCMS results shown in Figure 6 reveals that oil contains aromatics and hydrocarbons as major chemical compounds.

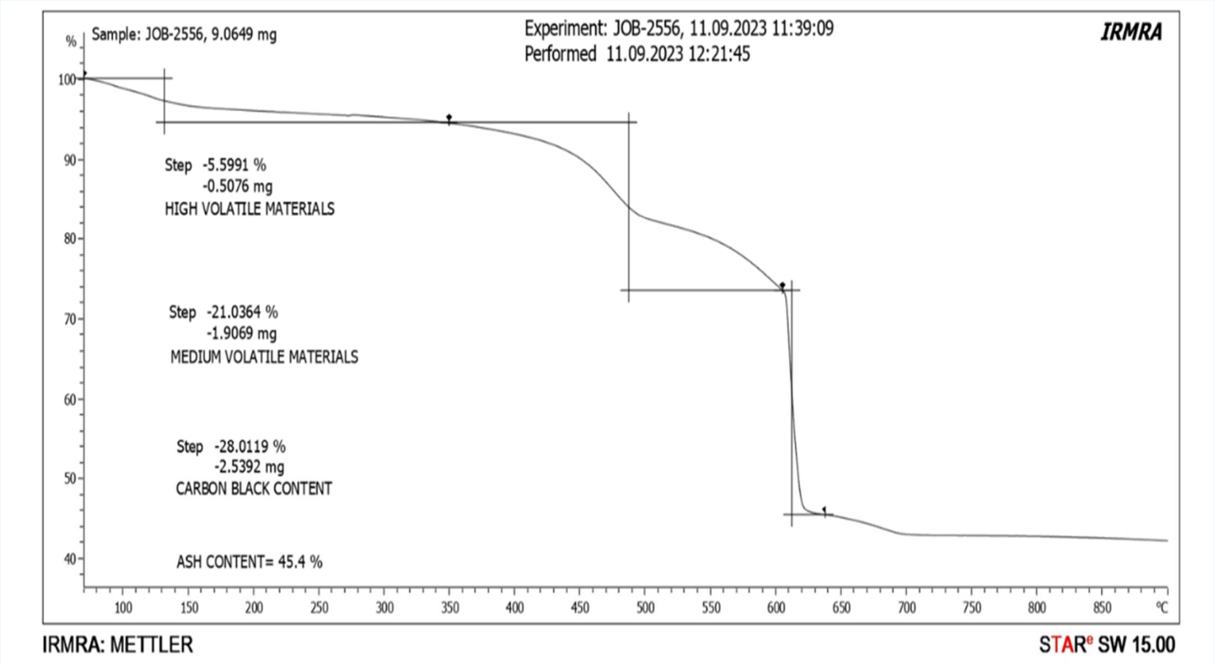
Figure 6: Chemical composition of paper plastic crude oil



From oil characterization, it was observed that produced paper plastic oil is a source of fuel and chemical value, and it can be upgraded to commercial diesel grade fuel using separation technologies.

Char characterization: The char is another important product from the process of paper plastic feedstock, and it also has desired properties for different applications. The char also contains aluminium foil in good amount which can be recycled to the aluminium industries. The char was characterized using TGA analysis, FTIR, FESEM and EDS. TGA analysis confirms that char contains around 55% of volatile matter and 45% of fixed carbon with ash content. char also contains important functional groups useful for applications in rubber compounding and as adsorbent

Figure 7: Thermogravimetric analysis of paper plastic char



Formulation of Rubber compounding - partial replacement of Carbon black with char

Biochar sample was tested as per formulation given in Table -3.

Table – 3: Rubber Compound Formulation

Compounding Ingredient	Blank	Control	5%	10%	20%	100%
SBR1502	100	100	100	100	100	100
Zinc Oxide (ZnO)	3	3	3	3	3	3
Stearic Acid (SA)	2	2	2	2	2	2
Carbon Black- SRF (N774)	0	50	47.5	45	40	0
Biochar	0	0	2.5	5	10	50
Accelerator - CBS	1.5	1.5	1.5	1.5	1.5	1.5
Accelerator - TBBS	1.5	0.5	0.5	0.5	0.5	0.5
Curing agent - Sulphur	1.5	1.5	1.5	1.5	1.5	1.5

While all other ingredient of the formulations are same for all formulations i.e. SBR 1502 -100phr, ZnO-3phr, Stearic Acid-2phr, CBS-1.5phr, TBBS-1.5phr & Sulfur-1.5phr

Mixing:

Mixing was done on open two-roll mill, Lab mill (12 X 16”) at room temperature, with friction ratio of 1:1.25. Initially polymer was masticated for 2 minutes, followed by addition of ZnO and SA, for further 2 minutes. After that filler (Carbon black or Biochar or mixture of both as per formulation given in table 1) was added and further masticated for 3 minutes. Master batch refining was done for 2 minutes by keeping nip gap approx. 1mm. Master batch was cooled at Room temperature before addition of accelerator and curing agents. Accelerators were added in master batch on cooled rolls. While adding accelerator and curatives, nip gap is kept approx. 1mm and masticated for 4 minutes. For all compounds, final sheet taken out from approx. 3.8mm nip gap. All compounds were conditioned for 24hrs at room temperature and then submitted for characterization. Details of the same in given in table-4

Table – 4: Mixing Sequence

No.	Activity	Duration (minutes)	Accumulative (minutes)
1.	Polymer mastication , mill opening at 1.1 mm	2.0	2.0
2.	Add the ZnO +SA	2.0	4.0
3.	Add Carbon Black or Biochar or mixture of both as per formulation	3.0	7.0
4.	Add Accelerators + Curing agent	4.0	11.0

Properties on Vulcanized Rubber compound:

For testing properties on vulcanized rubber compounds, rubber slab and other samples were cured at 160°C as per curing time given in table 5

Table-5 – Curing time in minutes @160°C temperature

Sr. No.	Description	Blank	STD	5%	10%	20%	100%
1.	Molding time for slab, minutes	15	11	12	15	14	14
2.	Compression Set Button Molding time, minutes	25	21	22	25	38	24

All the moulded samples are free from visible defects.

Testing of Moulded compound samples:

Moulded samples were preconditioned at room temperature before further testing. Test results and Properties of the moulded compound samples after replacement of carbon black (STD) with different proportions of char and test standards followed for different parameters are shown in table -6

Tabel 6: Properties of the moulded Rubber compound sample after partial replacement with char

Sr. No.	Properties tested	Test Standard	Blank	STD	5%	10%	20%	100%
1.	Physical Properties on sample							
i)	Hardness (Shore A)	ASTM D2240	46	64	63	63	61	56
ii)	Modulus at 100% (Kg/sq.cm)	ASTM D412	10	21	21	20	17	12
iii)	Modulus at 200% (Kg/sq.cm)		17	47	40	40	32	14
vi)	Modulus at 300% (Kg/sq.cm)		14	83	72	69	56	16
v)	Tensile Strength (Kg/sq.cm)		26	189	181	180	161	34
vi)	Elongation at break (%)		310	555	550	570	610	750
vii)	Tear Strength (kg/cm)	ASTM D624	13	61	61	57	51	19
2.	Change in mechanical Properties after air ageing at 70°C for 72hrs – ASTM D573							
i)	Hardness (Points)	ASTM D2240	50	65	64	64	63	57
ii)	Modulus at 100% (Kg/sq.cm) (%)	ASTM D412	10	23	25	22	20	14
iii)	Modulus at 200% (Kg/sq.cm) (%)		17	56	54	47	37	16
vi)	Modulus at 300% (Kg/sq.cm) (%)		21	102	92	82	65	18
v)	Tensile Strength (Kg/sq.cm) (%)		22	188	195	179	173	31
vi)	Elongation at break (%)		300	470	520	530	590	670
vii)	Tear Strength (kg/cm) (%)	ASTM D624	14	63	57	61	52	20
3.	Abrasion – Abrasion Resistance Index	IS-3400 (pt-3)	-	168	144	130	99	55
4.	Abrasion - Relative Volume Loss (mm3)		-	81	94	105	137	245
5.	De-Mattia – Cut Growth	ASTM D813	17.5	30.75	35	35	40	8.4
6.	Compression Set @RT/25% deflection/72hrs	ASTM D395 method B	15	16	17	16	21	26
7.	Compression Set @70°C/25% deflection/24hrs							
8.	Specific gravity	ASTM D297	0.976	1.14	1.14	1.14	1.13	1.13

From the test results shown in table 6 it could be concluded that there could be possibility of partial replacement of conventional semi reinforcing grade carbon blacks by char up to 10% without compromising the quality of the rubber compound which could find use in non critical applications, in a variety of industrial rubber compounds such as Conveyor belts, Hoses, tape, Shoe soles, heels, various Molded products like O rings, Gaskets, Sheets, Rubber mats etc. Thus partial replacement of carbon black resulting from thermo-chemical treatment would help in reduced dependence on petroleum based fossil fuel and carbon footprints.

Conclusion:

Thermo-chemical treatment under controlled environment, holds great potential for its conversion in to value added products and an approach towards recovery of resources from waste plastic from paper industry and good example of circular economy. It is a process in which the mixed plastic waste under controlled process conditions breaks it down into its constituent hydrocarbons (monomers). Primarily oil (fuel) is extracted along with non-condensable gases and char. The produced oil has high calorific value and may be used as a fuel in industrial burners and electricity generators. The solid carbonaceous char obtained as a by-product may be used as replacement of carbon black in rubber compounding in rubber industry. The non-condensable gases will provide heat energy to the endothermic degradation process and makes the technology self-sustainable with respect to energy requirement. Efforts are being made to make the process techno-economically feasible and environmentally sustainable. Despite these facts, the process may be considered as a viable option to handle the current plastic waste and extract value added resources.

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