World Environment Day: Thematic Session
Himalayan Eco-system

Upcycling of Waste Plastics into Graphene: An Innovative approach towards “Waste to Wealth”

Presented

By

Dr. Nanda Gopal Sahoo
(Principal Investigator)
Nanoscience & Nanotechnology Centre
Department of Chemistry
Kumaun University
Nainital, Uttarakhand
Waste is currently a major issue worldwide, becoming more and more important in developing countries (China, India, etc.) as well as in Europe.

Different types of waste can be categorized into industrial, agricultural, sanitary and solid urban residues based on their origin.

Especially in India plastic waste is still in their traditional position because of the huge technological gap.

**Plastic Processing in India (MMTPA)**

Source: Industry Reports, Tata Strategic Analysis
Plastic waste consumption in India

- India rate of recycling of plastic waste is the highest (60%) in the world as compared to other countries (China 10%, Europe (7%), Japan (12%), South Africa (16%), USA (10%).
- Plastic waste is recycled in India in unorganised way.
Plastics: Blessings or Curse?

Plastics:
- Resistant
- Durable
- Insulator
- Inexpensive
- Easy to produce

Solid plastic waste

Huge environmental pollution

Health hazards of plastics:
- Humans: Cancer, Endocrine problems, Skin Problems, Disruption in sexual fertility, Hypothyroidism
- Animals: Chokes sea animals, Ulcers, infections or death in birds
Plastics waste in Nainital Region

Is plastic waste can be used as source for value added products????
Our Vision

- “Environmental assessment and management”
- “Promotion of micro-entrepreneurship and greener technologies”
- Upcycling of waste materials for “Waste to Wealth”

BEFORE

AFTER

WE CAN MAKE THIS HAPPEN!
Plastic waste as Raw Materials for “Waste to Wealth”

Why should Plastic waste be used as a raw materials?

- Public safety & customer demand
- Functionalized carbon materials
- Availability anywhere in different concentration
- Reduced the carbon footprint and dependence on fossil resources
- Renewable
Selection of Effective Steps for Plastic Waste Upcycling

Plastic waste

- Energy recovery
  - Heat and power Generation
  - Fuel for automobile industry
- Material recovery
  - Mechanical recycling
  - Feedstock recycling
  - Biological recycling

Plastic: selectively rich source of carbon

Carbon nanomaterials “GRAPHENE”

Additive for concrete mixture
**Objectives**

- **Synthesis of Graphene from the plastic waste for the energy and biomedical applications and to develop new cheaper and greener techniques for the mass production of Graphene from plastic waste.**

- **Conversion and collection of the fuel from the plastic waste for the automobile and other similar industrial applications using the same, by using specially design multipurpose waste recycling machine.**

- **Secondary stage plastic (semi liquid plastic) to be utilized for making additives for high standard concrete.**
Methodology

Waste plastics

Categorization

PET, HDPE, LDPE, PS, PP and other

Washing, Major Cutting, Minor Cutting, Drying

In SWAYMBHU-WRM-2021

Part (A)

Hot thermal Treatment

Semi Liquid Plastic

Laboratory Treatment to get additives for concrete mixture

Part (B)

Pyrrolysis in waste recycling machine in presence of catalyst at high temperature within inert atmosphere

Value added fuel + Carbon Nano materials
Our First Step towards “Waste to Wealth”

Our Primary step towards this movement of clean India Mission by Up-cycling of waste plastics (2016)

Additives for concrete mixture

Cost effective waste management set up at Nainital, Uttarakhand, India

Preliminary Waste Management Set-Up @ NSNT Nainital
Graphene nano sheets form waste plastics
Graphite (3D) – stacking up graphenes

Graphene (2D) – the mother of graphites

The basic block for carbon nanotubes (1D) (folding up graphene) and C60 (0-D) bucky ball
### Properties of Graphene

<table>
<thead>
<tr>
<th>Property</th>
<th>Graphene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (GPa)</td>
<td>~130</td>
</tr>
<tr>
<td>Young Modulus (TPa)</td>
<td>&gt;0.5-1</td>
</tr>
<tr>
<td>Electrical Conductivity (S/m)</td>
<td>$10^4 - 10^8$</td>
</tr>
<tr>
<td>Surface Area (m²/g)</td>
<td>2700</td>
</tr>
</tbody>
</table>

### Challenges

**Production**
- Difficulty in high-quality and high-uniformity management
- Time-consuming synthesis process
- Difficulty in the mass production
(a) Raman spectra of graphene nano sheets (experimental); (b) Computational Raman spectrum from modeling (c) Hexagonal structure of graphene nano sheets shows two main types of edges: Zig-zag and armchair (d) TGA curve of graphene nano sheets
Characterization

(a) FT-IR spectrum of graphene nano sheets  
(b) XRD spectrum of graphene nano sheets  
(c) UV-vis spectrum of graphene nano sheets
Characterization

E. AFM image of charred residue

F. AFM image of charred residue (Stack view)

G. TEM image of charred residue

H. TEM image of charred residue
Electronic properties

(a) 6*6 periodic hexagonal cell of graphene nano sheet and (6) The pristine graphene shows perfect zero band gap at the K-point of brillouin zone and (c-f) In all the defect cases (the bands are observed to cross the Fermi level, which indicates the metallic nature of these defected sheets.
Quantum capacitance ($C_Q$) of graphene with different structural imperfections (defects) extracted from their respective electronic density of states (DOS)

<table>
<thead>
<tr>
<th>Defect Concentration</th>
<th>Formation Energy $E_F^L$ (eV/Å)</th>
<th>Electronic Nature</th>
<th>Peak $C_Q$ (uF/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pristine Graphene</td>
<td>-</td>
<td>Zero band gap</td>
<td>18.85</td>
</tr>
<tr>
<td>1.38 %</td>
<td>0.56</td>
<td>Metallic</td>
<td>214.16</td>
</tr>
<tr>
<td>4.16 %</td>
<td>0.77</td>
<td>Metallic</td>
<td>209.37</td>
</tr>
<tr>
<td>6.94 %</td>
<td>1.04</td>
<td>Metallic</td>
<td>203.70</td>
</tr>
<tr>
<td>9.72 %</td>
<td>1.36</td>
<td>Metallic</td>
<td>101.10</td>
</tr>
</tbody>
</table>

Table: Formation energy per unit length of sheet, electronic nature and peak quantum capacitance of graphene with different defect concentration.

<table>
<thead>
<tr>
<th>Element</th>
<th>Line Type</th>
<th>k Factor</th>
<th>Absorption Correction</th>
<th>Wt%</th>
<th>Wt% Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>K series</td>
<td>2.781</td>
<td>1.00</td>
<td>76.99</td>
<td>1.30</td>
</tr>
<tr>
<td>O</td>
<td>K series</td>
<td>2.028</td>
<td>1.00</td>
<td>23.01</td>
<td>1.30</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td></td>
<td></td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Table: shows the data obtained through the EDX spectroscopy
Raman Analysis at different conditions
Raman analysis at different conditions
UV Analysis at different Conditions

(a) sample-1
(b) Sample-2
(c) sample3
(d) sample-4
(e) sample-5
UV Analysis at different conditions

(a) Sample-6

(b) Sample-7

(c) Sample-8
Estimation of Cost for One Time Running of SWAYAMBHU-WRM-2021

(1) Manpower- 03
  JRF-02
  Technical Staff-01
  JRF @ Rs 833.00
  Technical Staff @ Rs 600.00
  Total= 2*833+1*600= **Rs 2266 per Day**

(2) Raw Materials
  Waste plastics= @ 28 per kg
  Catalyst= @ 300 kg
  Solvent 1= 500 per Liter
  Solvent 2= 1000 per Liter
  Distilled Water= Rs 10 per liter
  Total cost of raw materials= 2800+900+500+500+200 = **Rs 4,900**

(3) Energy Consumption
  Diesel @ Rs 66 per liter
  Electricity @ Rs 6 per unit
  Total= 132+300= **Rs 432**

(4) Water + cleaning agent consumption
  Total = **Rs 350**

(5) Maintenance charges
  Total = **Rs 500**

(6) Travel
  Rs 1000.00

(7) Other Charges
  Rs 500.00

Overall Cost: **Rs. 9,948.00/- only**
Capacity and Outcomes of SWAYMBHU-WRM-2021

- Capacity – 100 kg/day
- Expected outcomes:
  - Graphene -15- 20 %
  - Liquid Fuel - 25-30 %
  - Gaseous fuel- 35-45%

- First phase trial:
  - Waste plastic: 15 kg (Mixed plastic)
  - Graphene: 2.5-3.0 kg
  - Liquid fuel: 3.5-4.5 L
  - Gaseous fuel : Used for running the machine for 40 min
  - Repeatability: Three times

- Second phase trial:
  - Waste plastic: 15 kg (PET bottles)
  - Graphene: 3.0- 4.0 kg
  - Liquid Fuel : ----
  - Gaseous fuel: Used for running the machine for 1 hr
  - Repeatability: Three times
Market of Graphene

<table>
<thead>
<tr>
<th>Pack Size</th>
<th>Price (INR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G (15-20 layer)</td>
<td>9,566.12</td>
</tr>
<tr>
<td>10 mg (Single layer)</td>
<td>13881.00</td>
</tr>
</tbody>
</table>

Global Manufacturing of Graphene by method and by country
(75 manufacturing organisations)

Total Graphene Market will Reach $126 million in 2020

Source: Lux Research, Inc.
Potential Applications of Graphene

**Energy Storage**
- Super Capacitors
- Batteries

**Controlled Drug Delivery/Release**

**Microelectronics**
- Flexible LED Displays
- Micro actuators
- Conductive Composites

**Green Energy Applications**
- Fuel Cells
- Wind Turbines
- Solar Cells

**Structural Applications**

**Aerospace Applications**

**Maritime Applications**

- Polymer nanocomposites
- Water Purification

**Microelectronics**

- Flexible LED Displays
- Micro actuators
- Conductive Composites
Upcycling of waste plastics into value added products such as graphene, liquid fuel, gaseous fuel and concrete mixture by single step process

- Cost effective and Greener technology
- High revenue
- Multidisciplinary applications through one process
Real world waste plastic can become a promising candidate for the synthesis of carbon nanomaterials.

Our method can be solved the various environmental issues caused by the waste plastic.

The waste is recyclable, but remember it may be a kind of silent poison. So be aware while using such materials our day to day life. So, we also conducted several plastic awareness programs at the project site.
Research Group

Web site: www.ngsahooresearchgroup.in
Everyone must be his own scavenger.

M. K. Gandhi

The Mind of Mahatma Gandhi, p. 200
Healthy, well-informed, balanced criticism is the ozone of public life.

M. K. Gandhi

MAHATMA, Vol. 4, p. 206

Thank You