# Elaboration and characterization of conductive polymer nanocomposites with potential use as electrically driven membranes

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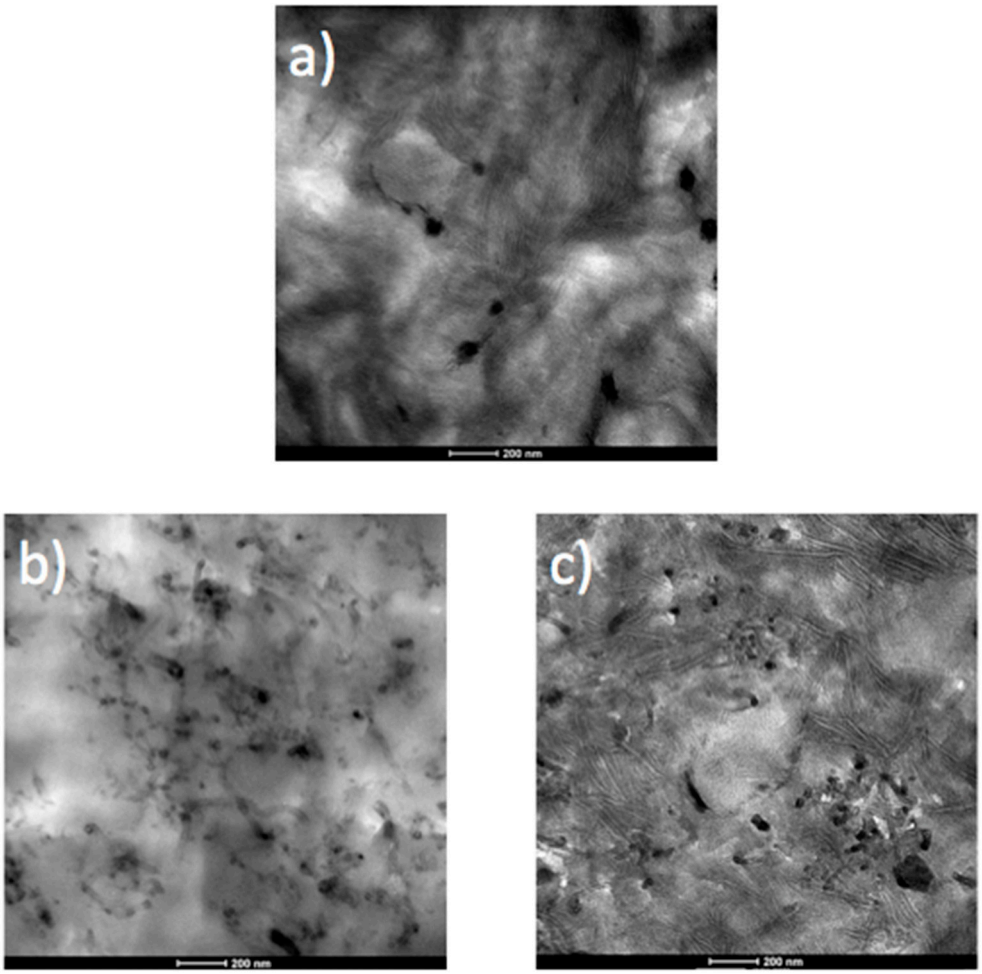


Figure S1. TEM images of the recycled PE and the different polymer/CNT nanocomposites. (**a**) Rec-PE, (b) PE/CNT and (c) Rec-PE/CNT.

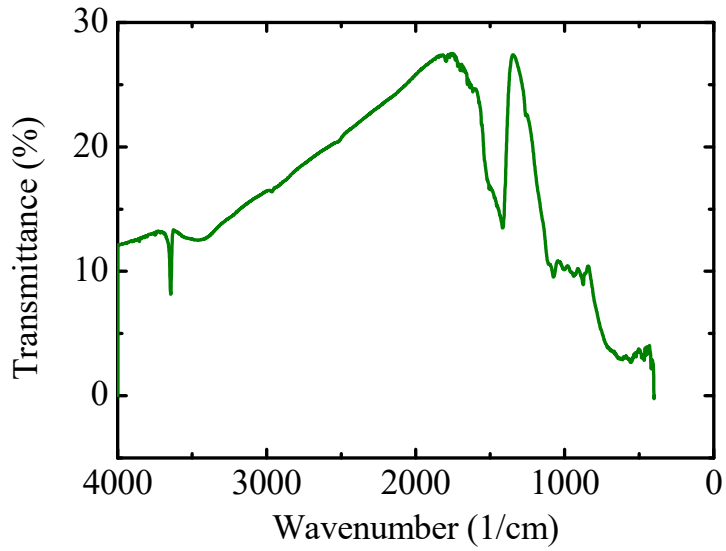


Figure S2. Infra red spectroscopy of Rec-PP sample residue after being carboniced.

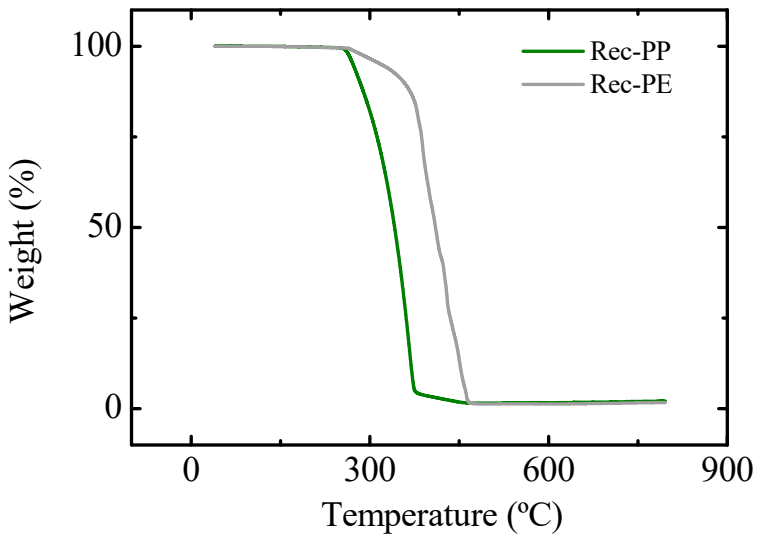


Figure S3. The weight loss obtained by TGA for recycled PP (Rec-PP) and recycled PE (Rec-PE).

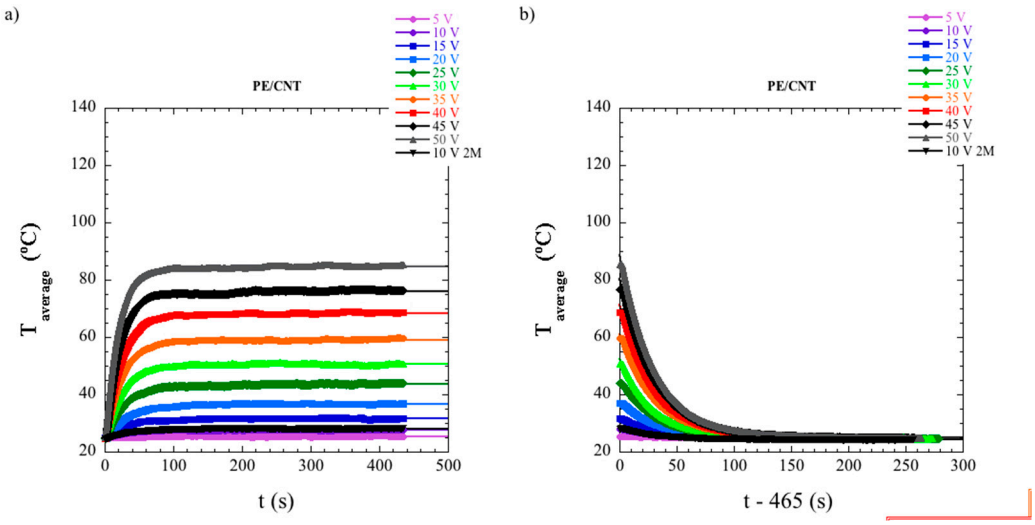


Figure S4. The heating and cooling step of the Joule heating effect is shown for PE/CNT. The data are fitted to equation 1 in the case of the heating step and to equation 3 for the cooling process. 10 V 2M stands for a second measurement carried out applying 10 V after a first run, to test reproducibility.

Table S1. Different parameters obtained using equation 1-3 for PP/CNT, $h_{r+c}$ is the heat transferred by radiation and convection, $\tau_h$ and $\tau_c$ are a characteristic time, corresponding to heating and cooling respectively. $C_p$ is the specific heat capacitance $\left(C_p = \frac{\tau}{R_{th}m}\right.$, where m is the weigth$\left.\right)$ and $R_{th}$ is the thermal resistance ($R_{th} = \Delta T/P$). All the parameters have been obtained from the heating except $\tau_c$. 10 V 2M stands for a second measurement carried out applying 10 V after a first run, to test reproducibility.

| PP/CNT | | | | | |
|---|---|---|---|---|---|
| V | $h_{r+c}$ | $C_p$ | $R_{th}$ | $\boldsymbol{\tau_h}$ | $\boldsymbol{\tau_c}$ |
| V | mW ºC$^{-1}$ | J g$^{-1}$ K$^{-1}$ | ºC W$^{-1}$ | s | s |
| 2.5 | 34.0 ± 15.1 | 1.56 ± 0.29 | 117.0±56.2 | 37.1±10.7 | 41.5±12.0 |
| 5 | 37.6 ± 4.7 | 1.65 ± 0.19 | 94.4±17.4 | 32.8±1.6 | 30.6±2.2 |
| 7.5 | 37.1 ± 1.8 | 1.51 ± 0.01 | 93.7±1.6 | 30.1±1.2 | 30.7±0.7 |
| 10 | 33.2 ± 3.2 | 1.21 ± 0.20 | 108.0±10.6 | 27.8±2.4 | 29.8±0.6 |
| 12.5 | 38.1 ± 2.4 | 1.31 ± 0.16 | 92.2±8.0 | 25.7±1.4 | 30.2±1.1 |
| 15 | 34.5 ± 1.9 | 1.08 ± 0.14 | 102.2±9.2 | 23.3±1.4 | 29.4±1.1 |
| 17.5 | 36.5 ± 4.0 | 1.06 ± 0.07 | 97.1±8.8 | 21.9±0.9 | 29.0±0.2 |
| 20 | 39.6 ± 1.8 | 1.05 ± 0.11 | 88.8±6.6 | 19.8±1.0 | 29.1±0.1 |
| 10 2M | 33.6 ± 3.9 | 1.14 ± 0.15 | 107.5±14.6 | 25.9±0.5 | 29.2±0.6 |

Table S2. Different parameters obtained using equation 1-3 for Rec-PP/CNT Powder, $h_{r+c}$ is the heat transferred by radiation and convection, $\tau_h$ and $\tau_c$ are a characteristic time, corresponding to heating and cooling respectively. $C_p$ is the specific heat capacitance $\left(C_p = \frac{\tau}{R_{th}m}\right.$, where m is the weigth$\left.\right)$ and $R_{th}$ is the thermal resistance ($R_{th} = \Delta T/P$). All the parameters have been obtained from the heating except $\tau_c$. 10 V 2M stands for a second measurement carried out applying 10 V after a first run, to test reproducibility.

| Rec-PP/ CNT | | | | | |
|---|---|---|---|---|---|
| V | $h_{r+c}$ | $C_p$ | $R_{th}$ | $\tau_h$ | $\tau_c$ |
| V | mW $^oC^{-1}$ | J $g^{-1}$ $K^{-1}$ | $^oC$ $W^{-1}$ | s | s |
| 5 | 601.4±422.4 | 34.31±15.11 | 8.4 ± 4.7 | 66.3 ± 59.2 | 138.6±164.1 |
| 10 | 748.5±727.5 | 85.25±90.82 | 8.3 ± 11.2 | 41.8 ± 39.6 | 48.7±16.3 |
| 15 | 149.2±21.0 | 9.26±1.87 | 23.8 ± 4.4 | 44.3 ± 0.9 | 37.9±10.4 |
| 20 | 101.8±1.6 | 5.58±0.14 | 34.8 ± 1.0 | 39.8 ± 2.1 | 38.3±1.2 |
| 25 | 73.1± 5.6 | 4.10±0.12 | 50.2 ± 5.5 | 42.0 ± 3.5 | 34.2±0.5 |
| 30 | 60.3±6.3 | 2.97±0.46 | 58.0 ± 5.8 | 35.0 ± 1.8 | 35.2±0.8 |
| 35 | 53.0±4.1 | 2.41±0.52 | 66.3 ± 4.6 | 32.4 ± 4.7 | 34.8±0.2 |
| 40 | 79.4±6.2 | 3.40±0.20 | 43.8 ± 3.0 | 30.4 ± 0.2 | 34.8±0.4 |
| 45 | 82.4±12.6 | 3.60±0.19 | 43.4 ± 6.7 | 31.8 ± 3.3 | 33.7±0.2 |
| 50 | 76.9±11.6 | 2.98±0.46 | 46.4 ± 7.0 | 28.0 ± 0.0 | 33.2±0.0 |
| 10 2M | 180.9±16.3 | 10.20±3.27 | 18.7 ± 2.0 | 38.4 ± 8.3 | 38.2±0.7 |

Table S3. Different parameters obtained using equation 1-3 for PE/CNT, $h_{r+c}$ is the heat transferred by radiation and convection, $\tau_h$ and $\tau_c$ are a characteristic time, corresponding to heating and cooling respectively. $C_p$ is the specific heat capacitance $\left(C_p = \frac{\tau}{R_{th} m}\right.$, where m is the weigth$\left.\right)$ and $R_{th}$ is the thermal resistance ($R_{th} = \Delta T/P$). All the parameters have been obtained from the heating except $\tau_c$. 10 V 2M stands for a second measurement carried out applying 10 V after a first run, to test reproducibility.

| PE/CNT | | | | | |
|---|---|---|---|---|---|
| V | $h_{r+c}$ | $C_p$ | $R_{th}$ | $\tau_h$ | $\tau_c$ |
| V | mW $^oC^{-1}$ | J $g^{-1}$ $K^{-1}$ | $^oC$ $W^{-1}$ | s | s |
| 5 | 510.3±297.6 | 69.79±77.08 | 5.6±6.1 | 33.0±0.6 | 131.8±56.8 |
| 10 | 139.8±19.0 | 7.34±2.69 | 26.5±3.2 | 39.3±6.8 | 35.7±2.1 |
| 15 | 73.9±3.6 | 3.60±0.13 | 48.7±6.0 | 36.4±2.9 | 34.8±3.5 |
| 20 | 55.5±2.9 | 2.53±0.20 | 65.7±6.9 | 34.5±1.9 | 32.8±1.1 |
| 25 | 44.1±2.1 | 1.78±0.01 | 83.8±7.6 | 31.0±0.4 | 31.3±0.4 |
| 30 | 57.1±4.5 | 2.11±0.01 | 63.6±8.5 | 27.8±1.4 | 29.9±1.1 |
| 35 | 66.8±4.8 | 2.27±0.14 | 54.6±6.2 | 25.7±0.7 | 31.0±0.9 |
| 40 | 60.2±4.5 | 1.99±0.19 | 60.8±8.3 | 25.0±1.0 | 30.3±0.0 |
| 45 | 57.1±5.4 | 1.73±0.09 | 64.1±9.8 | 22.9±0.4 | 30.2±0.5 |
| 50 | 58.1 | 1.50 | 60.5 | 20.0 | 30.7 |
| 10 2M | 100.6 | 4.90 | 35.5 | 38.4 | 36.5 |

Table S4. Crystallinity of membranes employed for permeality measurements.

| Sample | $X_C$ (%) |
|---|---|
| PP | 51 |
| Rec-PP | 49 |
| PP/CNT | 49 |
| Rec-PP/CNT | 45 |
| PE | 75 |

| | |
|---|---|
| Rec-PE | 59 |
| PE/CNT | 70 |
| Rec-PE/CNT | 57 |

Table S5. Permeability of PP and PE systems at 25 °C.

| Sample | WVTR ((g mm)/($m^2$ day)) | P $O_2$ (Barrer) |
|---|---|---|
| PP | 2.67 ± 0.27 | 1.77 ± 0.20 |
| Rec-PP | 4.97 ± 0.36 | 3.09 ± 0.57 |
| PP/CNT | 0.95 ± 0.25 | 2.20 ± 0.09 |
| Rec-PP/CNT | 1.39 ± 0.27 | 3.18 ± 0.12 |
| PE | 2.32 ± 0.18 | 1.03 ± 0.04 |
| Rec-PE | 2.56 ± 0.32 | 1.48 ± 0.05 |
| PE/CNT | 1.04 ± 0.22 | 1.99 ± 0.06 |
| Rec-PE/CNT | 1.12 ± 0.16 | 2.45 ± 0.15 |

Table S6. Permeability prediction employing different models.

| Sample | PP/CNT | Rec-PP/CNT | PE/CNT | Rec-PE/CNT |
|---|---|---|---|---|
| Nielsen | 1.25 | 2.43 | 1.05 | 1.34 |
| Cussler regular | 1.36 | 2.86 | 1.18 | 1.63 |
| Bharadwaj | 1.79 | 3.22 | 1.55 | 1.83 |
| Gusev Lusti | 1.26 | 2.42 | 1.10 | 1.38 |

Table S7. Permeability of PP/CNT and Rec-PP/CNT at 25ºC and 32ºC.

| Sample | WVTR ((g mm)/($m^2$ day)) 25 °C | P $H_2O$ (Barrer) 25 °C | WVTR ((g mm)/($m^2$ day)) 32 °C | P $H_2O$ (Barrer) 32 °C |
|---|---|---|---|---|
| PP/CNT | 0.95 ± 0.25 | 575 ± 150 | 7.13 ± 0.95 | 2800 ± 340 |
| Rec-PP/CNT | 1.39 ± 0.27 | 840 ± 160 | 4.47 ± 0.51 | 1790 ± 270 |