# CHAPTER V
# CONCLUSION AND RECOMMENDATION

This thesis described the fabrication of supercapacitor using three kinds of commercially obtained CNTs and hybrid polymer electrolytes. At first, conductivity studies were conducted on two different kinds of aqueous polymer electrolytes (PSPE and HSPE) in order to ascertain their extents of effective conductivities for used in the fabrication of the supercapacitor. Their preparation was made prepared from the composition of PVA and $H_3PO_4$, with the PVA samples kept constant while varying the $H_3PO_4$ at 0 - 70 wt. % in the multiple of 10 (for PSPE) and immerse in a cellulose filter paper (in order to obtain HSPE samples). Both PSPE and HSPE showed an excellent of $2.56 \times 10^{-3}$ $Scm^{-1}$ and $1.67 \times 10^{-3}$ $Scm^{-1}$ respectively. These results were obtained at the optimum composition of 70 wt.%. Furthermore, from the overall results of the XRD analysis carried out on both categories of the samples revealed a semi-crystalline peak of the PVA decreases as the acid concentration increases. Which in turns indicated that, there is an enhancement in the amorphicity of the samples responsible for the process of ion transport. Furthermore, the degree of crystallinity calculated from the XRD peaks revealed that, the lower the degree of crystallinity, the higher the conductivity. Hence, the result was in consistent with XRD pattern of the samples, as the XRD peaks decrease with the decreasing percentage crystallinity. However of the 16 different samples (eight each for the PSPE and HSPE), three samples with the highest conductivity from HSPE were selected for use in the fabrication process, they are H50, H60 and H60.

Secondly, after extensive studies of the, polymer electrolytes was conducted, a fabrication of supercapacitor from three different commercially prepared Multiwalled

CNTs namely CPCMWCNTs, CPHMWCNTs and CPNMWCNTs. Within each of the aforementioned CNTs, three cells were constructed. This brings the total number of cells to nine.

This researcher was able to show detail fabrication processes of the carboxyl type of CNTs (CPCMWCNTs) that three cells were constructed and labeled as cell-A (C90PVdF-HFP10 |H50| C90PVdF-HFP10), cell-B (C90PVdF-HFP10 |H60| C90PVdF-HFP10) and cell-C (C90PVdF-HFP10 |H70| C90PVdF-HFP10) with changes in the separator. From the overall results for the electrochemical analysis of the CV, cell – C delivered highest capacitance of 313 $Fg^{-1}$ by more than 3 folds over cells A and B, within a voltage window of 0.0 –1.0 V. This result, as mentioned earlier, is attributed to the remarkable increase in conductivity of the electrolyte used (H70) which has the highest conductivity over H50 and H60 used in the assembly of cell A and B respectively. This was further proved by the CD analysis where cell – C shows perfect linear characteristic implying a formation of good electrode/electrolyte interface with a well-defined conductivity. In addition, no ohmic drop is observed in the profile delivering the highest specific capacitance of 153.00 $Fg^{-1}$ and a specific energy and power densities of 76.50 $Whg^{-1}$ and 1.00 $Wg^{-1}$ respectively, and attained the overall columbic efficiency of 93.8 %.

Furthermore, of the three cells that were successfully fabricated from Hydroxyl CNTs (CPHMWCNTs) and which were labeled as cell-A (H90PVdF-HFP10 |H50| H90PVdF-HFP10, cell-B (H90PVdF-HFP10 |H60| H90PVdF-HFP10 and cell-C (H90PVdF-HFP10 |H70| H90PVdF-HFP10), cell – C delivered highest capacitance of 92 $Fg^{-1}$ also by more than 3 folds over cells A and B using CV analysis, measured within a voltage window of 0.0 – 1.0 V. Furthermore, when measured by the CD analysis, this cell shows a better linearity characteristic implying a formation of good electrode/electrolyte interface with a well-defined conductivity with a very little IR drop observed in the profile, and delivering the highest specific capacitance of 99 $Fg^{-1}$ and a specific energy and power densities of 49.50 $Whg^{-1}$ and 0.13 $Wg^{-1}$ respectively, and attained the overall Columbia efficiency of 92.5 %.

Finally, the same analysis was done to the Normal CNTs (CPNMWCNTs), where three cells coded as cell-A (H90PVdF-HFP10 |H50| N90PVdF-HFP10), cell-B (N90PVdF-HFP10 |H60| N90PVdF-HFP10) and cell-C (N90PVdF-HFP10 |H70| N90PVdF-HFP10) were fabricated. From the overall of the electrochemical analysis of CV results, cell-C delivered the highest capacitance of 229 $Fg^{-1}$. While for the CD analysis of all the cells conducted within a voltage window of 0 – 1 V, cell-C also delivered better discharge capacitance of 144 $Fg^{-1}$ with highest energy and power densities of 70.50 $Whg^{-1}$ and 1.00 $Wg^{-1}$ respectively. The cell efficiency was calculated to be 90.2 %.

Overall, it can be seen that, cell-C of the carboxylic type of the CNTs delivered the highest capacitance, energy and power densities over all the remaining cells. It was already stated that, the introduction of surface carboxyl groups can create more than 3 times larger capacitance due to the increased hydrophilicity of MWCNTs in an aqueous electrolyte. Therefore, this could be one of the possible factors for its outstanding capacitance.

Here, it is also important to add that, as a typical supercapacitor, the performance of the CNT-based supercapacitor is closely related to the physical properties of the CNTs, such as specific surface area. However, it is clear that the specific surface area is not the sole dominant factor in the performance. The capacitance of the CNTs is affected by various factors, including specific surface area, pore size, pore size distribution, conductivity, etc. Only by optimizing these factors can improve its performance. This can be noticed from the three as-prepared CNTs used in this work. Although their specific area are the same (~ 43 $m^2g^{-1}$), their differences in the outer diameters and most importantly the conductivity of the electrolytes used have influenced their performance.

## 5.1 Recommendations

The research that we led on this topic raised some interesting questions that need to be answered so as to further improve our understanding of CNTs as a double layer capacitor electrode.

- During this research, we successfully fabricated CNT electrodes which were all commercially obtained. We though developing or growing our own CNTs will definitely enhance our understanding of how it's grown, and other characteristics might also reveal out to us.

- Aluminum foil and Perspex used in the assembly played befitting roles. Their low cost and wide familiarity of the current capacitor industry with these materials suggest relatively easy industrial and academia acceptance. However, due to a variety of applications, need to consider other options might also be a welcome idea.

- The electrolytes we used so far is HSPE which are made from a mixture of $H_3PO_4$ and PVA, both with different percentage ratio. Introduction of the IL into this mixture might contribute in obtaining supercapacitor of higher capacitance.

- Although the specific capacitances of the supercapacitors showed promising results, the power and energy densities did not really reach our target. This is unconnected with the aqueous electrolytes used. It is a known fact that the electrochemical window of this type of electrolyte is 0.0 – 1.2 V. In view of the above, it is part of future plans to employ other types of electrolytes that can have more electrochemical windows for consequent improved power and energy densities.