Chapter 7

Conclusion & Future work

7.1 Conclusions

The thesis presented explores the importance and applicability of the PVDF polymer based hybrids. The importance of energy harvesting as a sustainable green alternate energy source is being demonstrated through different ways. The growing need of the alternate energies for the sustainable future is prime concern of the world and even small contribution towards that would be appreciable. Energy harvesting is possible through different sources which are being ignored or left unattended. Harvesting energy through the mechanical or vibrational source is a green way to generate considerable amount of energy which does not involve any residual byproduct which could harm the environment. The utilization of different waste energies can generate substantial amount of electrical output which is beneficial for the small electronic devices and also is a potential source which can replace the existing batteries which is of harm after its usage. Polymer as a potential material for the energy harvesting is of great application due to its higher mechanical flexibility, durability, economic and lower density. Poly (vinylidene fluoride) is an exceptional polymer for energy harvesting based applications due to its ability to get transformed from the non-polar phase to piezo-active phase with some processing techniques.

In the thesis, PVDF based hybrids is prepared which is used for energy harvesting applications. The incorporation of the electroactive fillers and processing techniques leads to conversion of the non-piezo phase to electroactive phase which is being confirmed through different characterization techniques for efficient energy harvesting. The prepared hybrid has been designed to device form which is being implemented for measurement of electromechanical response drawing some practical applications. The key findings and conclusive remarks for the thesis are being discussed below:

Chapter 3 of the entitled thesis explains the importance of the induced piezoelectric phase in presence of the electroactive fillers. Here two piezoelectric fillers, namely tomato peel (TP) and cotton (CTN), are being added to form a hybrid with PVDF. The preparation of the polymer-based hybrid was performed through solution route. Despite being a piezoelectric material, TP could not enhance the electroactive content in the PVDF-TP hybrid as compared to the hybrid made from PVDF-CTN. The major reason behind the enhancement of the piezoelectric phase is the induction phenomenon which is higher in case of CTN which is being revealed through structural and thermal analysis. The higher induction of the polar phase content in the PVDF-CTN leads to higher output voltage and current of 65 V and 2.1 μA respectively as compared to the 23 V and 0.7 μA of output voltage and current respectively for the PVDF-TP. Hence the induced piezoelectricity in presence of electroactive filler like CTN is being explained which leads to better energy harvesting applications.

In **chapter 4**, electrospun PVDF and nanoclay (Cloisite 30B) nanofibers is being prepared at different weight ratios of the nanoclay. Electrospinning process is being used in which the effect of mechanical stretching and poling leads to enhanced electroactive phases. Incorporation of the nanoclay leads to better quality fibres as compared to the pristine PVDF but after a certain concentration (15 wt. %) of nanoclay the quality of fibres is reduced. Hence using the optimized parameters and concentrations, the prepared electrospun nanofibers is analysed structurally, mechanically and thermally to observe the effect of the nanoparticle addition and enhancement in piezoelectric content. A device is being prepared form the electrospun scaffolds which generated maximum output voltage and power density of 70 V and 68 μWcm^{-2} respectively. The ability of the device to harness energy from different human motions is also explained.

Chapter 5 shows the effect of ionic liquid (IL) in enhancement of the piezoelectric property in the PVDF-based nanofibers. In this work, IL at different concentrations was incorporated with PVDF and nanofibers were developed through electrospinning process. Addition of IL imparts better conductivity to the solution which leads to better fiber formation. The better quality fibre suggests the transformation of the non-polar phase to electroactive phase which is confirmed through the structural and thermal analysis. From the electrochemical analysis, the maximum ionic conductivity obtained for the nanohybrids is 0.18 mS.cm^{-1}. The maximum output voltage obtained is 48 V through finger tapping mode. The device is being used for generation of considerable energy from different human body movements explaining its applicability.

In **chapter 6**, carbon-based electroactive filler is being impregnated to the PVDF matrix through solution route which was used to develop nanofibers through electrospinning process. The carbon nanofiber (CNF) was being functionalized by sulphonating agent for better dispersion and enhanced properties. The functionalized CNF and PVDF nanohybrid produced better fibres from electrospinning process which confirmed the role of functionalization. Electromechanical response obtained from the sulphonated CNF and PVDF nanofibers was higher as compared to the neat PVDF and PVDF-CNF nanohybrids. Computational studies were also carried out revealing the better interaction of the piezoelectric filler with the PVDF. The maximum voltage (peak-to-peak) obtained for sulphonated CNF and PVDF was around 44 V while the maximum power obtained was around 57.2 μW. The fabricated device from the electrospun scaffolds was able to harness energy from different human motions and tribological forces. The device was able to store charges through capacitor and also glow LEDs on application of external stress. The practical applicability of the material was shown as voltage generation from the movement of cycle wheel.

7.2 Future Scope:

The present thesis explored the preparation and analysis of the PVDF-based hybrids through different techniques. The role of electroactive filler and processing methods were studied which resulted in the induction of the improved piezoelectric property. The energy harvesting properties and applications were demonstrated through different mechanisms. However there are different scopes and ways which can be utilised in future;

- Use of bio-based fillers which can be used for biomechanical energy harvesting.
- Develop methods to harness energy from the smaller frequency based sources.
- Hybrid preparation which can be used for different energy based applications.
- Designing and fabrication of the device for larger scale applications.
- Explore the material and principle for biological applications like bone regeneration, tissue engineering and others.