CHAPTER 8

CONCLUSIONS AND
SCOPE FOR FURTHER STUDY
8.1 Conclusions

Polymer blends and alloys are some of the most dynamic sectors of the polymer industry around the world in recent years. The annual growth rate of engineering polymer blends and alloys has been systematically outstripping that of the industry as a whole by a factor of 4 to 5. The main reason for the popularity, name and fame of these polymer blends and alloys is the ever-increasing cost of development of new polymers. It is estimated that developing a new polymer costs nearly US $15 million for research and development and an additional US $150 million in capital cost for a pilot plant. Polymer blending is quicker and less expensive. The development of a new polymer blend costs only a few million dollars. With little capital investment, the properties of blends can be tuned to satisfy a spectrum of customer demands.

The earliest polymer blends were prepared by exploiting the natural miscibility of component polymers. Blends of polyvinyl chloride with acrylonitrile rubber or polyphenylene ether with high impact polystyrene are good examples. Most of the polymer blends are immiscible in nature. Hence, the miscibility is still the main criteria for polymer blending. So, it is necessary to identify compatible, semi-compatible and non-compatible blends. When the blends are compatible, one can make tailor-made materials to suit a particular customer's demand. When the blends are semi-compatible or non-compatible, one can convert them into polymer alloys by studying the effect of suitable compatibilizers.

The solid state techniques like spectroscopy, thermal, mechanical, dielectric, diffraction and inverse gas chromatography are employed to study the miscibility of polymer blends. Most of these techniques though sophisticated are expensive, complicated and time-consuming. In these days, low cost, simple and rapid techniques are available to study the miscibility of polymer blends in solution. As it is already established that the solution techniques yield the same
information as the other solid state sophisticated techniques, the author decided to take up the present problem. In the present investigation, the author used solution techniques\textsuperscript{2-4} like viscosity, ultrasonic velocity, density and refractometric techniques for the study of nine different polymer blends at different temperatures. The author selected these techniques for their simplicity, low basic cost and rapidity and can be used even for routine analysis.

The thesis is comprised of Eight chapters, chapter 1 deals with the introduction and literature survey and chapter 2 deals with the water – soluble polymers and methodology and experimental techniques. From chapter 3 to chapter 7, the thesis deals with the results obtained by the author on nine blends at different temperatures selected by him. Chapter 8 gives overall conclusion on the miscibility of all nine blend systems.

**Chapter 1**

A brief introduction to the history of the development, miscibility, characterization and advantages of polymer blends is presented in this chapter. The literature surveyed by the author about the topic on polymer blends is given in the same chapter. The aim and scope of the research work are also discussed in this chapter.

**Chapter 2**

This chapter discusses briefly about the nature, properties, flow behaviour, significance and applications of water soluble polymers\textsuperscript{5,6}. This chapter also deals with the experimental techniques, theory and procedures relating to the miscibility of polymer blends. Then, the method of preparation of the blend solutions and the measurements of relative viscosity, ultrasonic velocity, density and refractive index of the polymer blends solution is described in this chapter.
Chapter 3

This chapter deals with the results obtained by the author on the miscibility studies of sodium alginate/polyvinyl alcohol blend at 30 °C, 40 °C and 50 °C. The molecular weight of sodium alginate was determined by gel permeation chromatographic method and found to be 4.96 KDa. The chemistry of sodium alginate and polyvinyl alcohol were discussed briefly. The interaction parameters $\mu$ and $\alpha$ based on Chee and Sun et al. approach respectively were computed. The $\mu$ values are negative when the sodium alginate content is up to 60% at 30 °C and 50% is the blend at 40 °C and 50 °C and then positive beyond these values. The interaction parameter $\alpha$ values are found to be negative when the sodium alginate content is up to 40% in the blend at 30 °C and 30% in the blend at 40 °C and 50 °C and then positive beyond these values. Based on most satisfactory and accurate Sun et al. method, the SA/PVA blend is found to be miscible only when the sodium alginate content is more than 50% in the blend at 30 °C and 40% in the blend at 40 °C and 50 °C. The existence of miscibility windows in the SA/PVA blend is due to the possible H – bonding between sodium alginate and polyvinyl alcohol. However, the temperature effect is so marginal on the miscibility of the SA/PVA blend. Hence SA/PVA blend is found to be semi-compatible in nature. These results were further confirmed by ultrasonic velocity, density and refractive index methods.

Chapter 4

This chapter presents the miscibility studies on the polymer blends of sodium alginate with polyvinyl pyrrolidone and sodium alginate and polyethylene glycol in water at 30 °C and 50 °C. The interaction parameters $\mu$ and $\alpha$ based on Chee and Sun et al. approach respectively were computed. The chemistry of polyvinyl pyrrolidone and polyethylene glycol were discussed briefly. Based on the criterion proposed by Chee, the interaction parameter $\mu$ values are found to be
negative when the sodium alginate content is up to 60% in the SA/PVP blend and 60% in the SA/PEG blend and the positive beyond these values. The computed interaction parameter $\alpha$, based on Sun et al criteria\(^8\), values are found to be negative when the alginate content is up to 50% in SA/PVP blend and 40% in the SA/PEG blend and positive beyond these values at 30 °C and 50 °C. Based on the above results, it can be stated that the SA/PVP blend is found to be miscible only when the alginate content is more than 60% in the blend and SA/PEG blend is found to be miscible only when the alginate content is more than 50% in the blend at both the temperatures. However, the temperature has no effect on the miscibility of SA/PVP and SA/PEG blends. The existence of miscibility windows in the SA/PVP blend is may be due to the possible H–bonding to some extent between the hydroxyl group of alginate and carbonyl group of polyvinyl pyrrolidone. In the SA/PEG blend, it may be due to the H–bonding to some extent between the hydroxyl groups of sodium alginate and polyethylene glycol. Ultrasonic velocity, density and refractometric methods further confirmed these results. Hence, SA/PVP and SA/PEG blends are found to be semi-compatible in nature.

**Chapter 5**

This chapter describes the miscibility studies on the polymer blends of sodium alginate with starch and sodium alginate with hydroxypropyl methylcellulose in water at 30 °C and 40 °C. The interaction parameters $\mu$ and $\alpha$ based on Chee\(^7\) and Sun et al\(^8\) approach respectively were computed. The chemistry of starch and hydroxypropyl methylcellulose were discussed briefly\(^5,6\). The interaction parameter $\mu$ values are found to be negative when the alginate content is up to 50% in both SA/ Starch and SA/HPMC blends and positive beyond these values at 30 °C and 40 °C, basing on the Chee’s method\(^7\). Using Sun et al\(^8\) method, the computed interaction parameter $\alpha$ values for the SA/Starch blend were found to be positive over the entire composition range at both
temperatures. Hence, SA/Starch blend is found to be compatible in nature. The compatibility of SA/Starch blend over the entire composition range may be due to the interaction between the hydroxyl groups of alginate and starch which leads to homogeneous continuous single phase system. However, the $\alpha$ values for SA/HPMC blend is found to be negative when the sodium alginate content is upto 20% in the blend and then positive beyond this value. So, SA/HPMC blend is found to be miscible only when the alginate content is more than 30% in it at both temperatures. Hence, SA/HPMC blend is semi-compatible in nature. The existence of miscibility windows in SA/HPMC blend may be due to the possible H-bonding to some extent between the hydroxyl groups of alginate and hydroxypropyl methylcellulose. However, the temperature has no effect on the miscibility of both the blends.

Chapter 6

This chapter deals with the miscibility studies on the polymer blends of methylcellulose with polyvinyl pyrrolidone and methylcellulose with polyethylene glycol in water at 30 °C and 35 °C. The interaction parameters $\mu$ and $\alpha$ based on Chee and Sun et al approach respectively were computed. The chemistry methylcellulose is discussed briefly. The interaction parameter $\mu$ and $\alpha$ values for MC/PVP blend were found to be negative when the methylcellulose content is upto 50% and positive beyond this value. Basing on Chee and Sun et al criterion, MC/PVP blend is found to be miscible only when the methylcellulose content is more than 60% in the blend at both temperatures. For MC/PEG blend, the interaction parameter $\mu$ and $\alpha$ values are found to be negative when the methylcellulose content is upto 60% and 40% respectively, and then positive beyond these values at 30 °C and 35 °C. Based on most accurate Sun et al criterion, MC/PEG blend is found to be miscible only when the methylcellulose content is more than 50% in the blend at both temperatures. The existence of these
miscibility windows may be due to H-bonding to some extent between hydroxyl groups of MC and carbonyl groups of PVP in MC/PVP blend and hydroxyl groups of MC and PEG in MC/PEG blend. However, the temperature has no effect on the miscibility of both MC/PVP and MC/PEG blends. Hence, MC/PVP and MC/PEG blends are found to be semi-compatible in nature.

Chapter 7

This chapter deals with the miscibility studies on the polymer blends of polyacrylamide /polyethylene glycol - 6000 and polyacrylamide/polyethylene glycol - 4000 in water at 30 °C. Polyacrylamide was synthesized in the laboratory as elsewhere. The interaction parameters $\mu$ and $\alpha$ based on Chee and Sun et al approach respectively were computed. The chemistry of polyacrylamide is discussed briefly. The interaction parameter $\mu$ value is found to be negative when the polyacrylamide content is upto 70% and 80% in PAAm/PEG - 6000 and PAAm/PEG - 4000 blends respectively and then positive beyond these values. However, $\alpha$ values based on Sun et al method are found to be negative over the entire composition range at 30 °C. So, both the blends are immiscible. The immiscibility may be due to the absence of H-bonding or dipole–dipole forces between amide group of PAAm and hydroxyl groups of PEG's. Hence, it can be stated that PAAm/PEG-6000 and PAAm/PEG -4000 are non-compatible in nature.

Chapter 8

This chapter gives the overall conclusion of the present investigation, uses, summary and further scope of the present research work.

To conclude, it is observed that the simple, low cost and rapid techniques such as viscosity, ultrasonic velocity, density and refractometric techniques can be effectively used for the miscibility studies of polymer blend in solution.
### SUMMARY

The following table summarizes the miscibility of some water – soluble polymer blends which are studied by the author.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Polymer blend systems at different temperatures</th>
<th>Existence of miscibility windows</th>
<th>Effect of temperature</th>
<th>Nature of the blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>SA/PVA</td>
<td></td>
<td></td>
<td>Semi-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
<td>When SA content is more than 50%</td>
<td>Only marginal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40 °C</td>
<td>When SA content is more than 40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 °C</td>
<td>When SA content is more than 40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>SA/PVP</td>
<td>When SA content is more than 60%</td>
<td>No effect</td>
<td>Semi-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C &amp; 50 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>SA/PEG</td>
<td>When SA content is more than 50%</td>
<td>No effect</td>
<td>Semi-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C &amp; 50 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>SA/Starch</td>
<td>Completely miscible</td>
<td>No effect</td>
<td>Compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C &amp; 40 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>SA/HPMC</td>
<td>When SA content is more than 30%</td>
<td>No effect</td>
<td>Semi-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C &amp; 40 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>MC/PVP</td>
<td>When MC content is more than 60%</td>
<td>No effect</td>
<td>Semi-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C &amp; 35 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>MC/PEG</td>
<td>When MC content is more than 50%</td>
<td>No effect</td>
<td>Semi-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C &amp; 35 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>PAAm/PEG-6000</td>
<td>Completely immiscible</td>
<td>-</td>
<td>Non-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>PAAm/PEG-4000</td>
<td>Completely immiscible</td>
<td>-</td>
<td>Non-compatible</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.2 Scope for further work

Nowadays, polymers are playing a vital role in almost all branches of industry. However, with the advancement of civilization, man is looking for new materials to meet his specific needs. The new materials should provide better properties and the preparation method should be available at affordable cost. Polymer scientists succeeded in generating many polymer blends, co-polymers and polymer composites to meet some of these demands. The polymer blending may result in the reduction of basic cost, enhancement of performance and improved processability.

In the present investigation, we have studied the following polymer blends.

i) Sodium alginate (SA)/Polyvinyl Alcohol(PVA)
ii) Sodium alginate (SA)/Polyvinyl Pyrrolidone (PVP)
iii) Sodium alginate (SA)/Polyethylene Glycol (PEG)
iv) Sodium alginate (SA)/Starch
v) Sodium alginate(SA)/ Hydroxypropyl Methylcellulose(HPMC)
vi) Methylcellulose (MC)/Polyvinyl Pyrrolidone(PVP)
vi) Methylcellulose (MC)/Polyethylene Glycol (PEG)
viii) Polyacrylamide (PAAm)/Polyethylene Glycol – 6000 (PEG-6000)
ix) Polyacrylamide (PAAm) /Polyethylene Glycol – 4000 (PEG – 4000)

Among the nine polymer blend systems studied, only sodium alginate (SA)/Starch is compatible in nature. Polyacrylamide (PAAm)/Polyethylene glycol – 6000 (PEG-6000) and polyacrylamide(PAAm) /Polyethylene glycol – 4000 (PEG-4000) are non-compatible in nature. All other polymer blend systems are semi-compatible in nature. These semi-compatible blend systems can be made
into compatible by using compatibilizers which leads to the formation of polymer alloys. Hence, there is a scope for the study of effect of compatibilizers on the miscibility of semi-compatible polymer blend systems.

Sodium alginate is a rigid and hydrophilic polymer. Hence, SA is used as membrane material for dehydration studies. Therefore, its membrane performance can be enhanced by blending SA with PVA, PVP, PEG, HPMC and Starch.

The films of all our blend systems having miscibility windows can be prepared and its miscibility studies can be checked by DSC and TGA analysis. The films of the polymer blends find applications in packaging material in food industry, (coating on tablets) in pharmaceutical industry etc.

Nowadays, water-soluble polymer blends and co-polymers are used as sugar clarificants in sugar industry. Therefore, clarification property of our polymer blends can be studied in sugar industry. These blends can also be used for controlled drug delivery studies.
8.3 References


5. *SBP Handbook of Industrial Gums and Resins*, SBP Board of Consultants and Engineers, Delhi (1998)


LIST OF PUBLICATIONS


