CHAPTER V
## CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aqueous ternary blend of AMP-PZ-MEA has revealed to be a promising amine solution for the capture of CO_2 from flue gas.

- From Figures 4.9 and 4.6, the various concentrations of the ternary blend of AMP-PZ-MEA showed higher equilibrium CO_2 loading (6.9 % to 19 %) and absorption working capacity (between 13.8 % to 48.3 %) compared to the conventional 5 M MEA.

- For all the tested AMP-PZ-MEA ternary blends, their rich solutions only experienced slight stickiness and no precipitation was formed even when their rich solutions were cooled at 20 °C for 480 hours.

- The two highly concentrated blends of AMP-PZ-MEA (2 M AMP – 1 M PZ – 3 M MEA and 2 M AMP – 1 M PZ – 4 M MEA) had higher absorption working capacity (5.4 % and 16.2 % respectively) than the optimal AMP-PZ binary blend of 3 M AMP – 1.5 M PZ (Figures 4.7 and 4.9). These three rich solutions (binary and ternary blends) were cooled at 20 °C for 480 hours without forming solid precipitates, but were slightly viscous (Figures 4.8 and 4.10). The non-precipitation of the ternary blend was attributed to its high H_2O/PZ molar ratio.

- AMP (high absorption capacity solvent) concentration was fixed at 2 M for all the ternary solvent blends analyzed. This is because of its viscosity, less reactivity than both PZ and MEA. This low concentration of AMP will both increase the equilibrium CO_2 loading and also minimizes the possibility of precipitation of the solution.

- PZ, the highly reactive primary promoter is in solid form (crystals) and has solubility limitations in water. Its maximum concentration in the ternary blend was limited to 1 M to avoid triggering precipitation. The reactive secondary promoter (MEA) is a non-viscous solvent was applied at a moderately low to moderately high concentration (2– 4 M) to increase the absorption working capacity of the ternary

blend solution (Figure 5.1). The limitation of PZ concentration (1 M) and use of MEA at moderate concentration both helped to retain a high H_2O/PZ molar ratio.
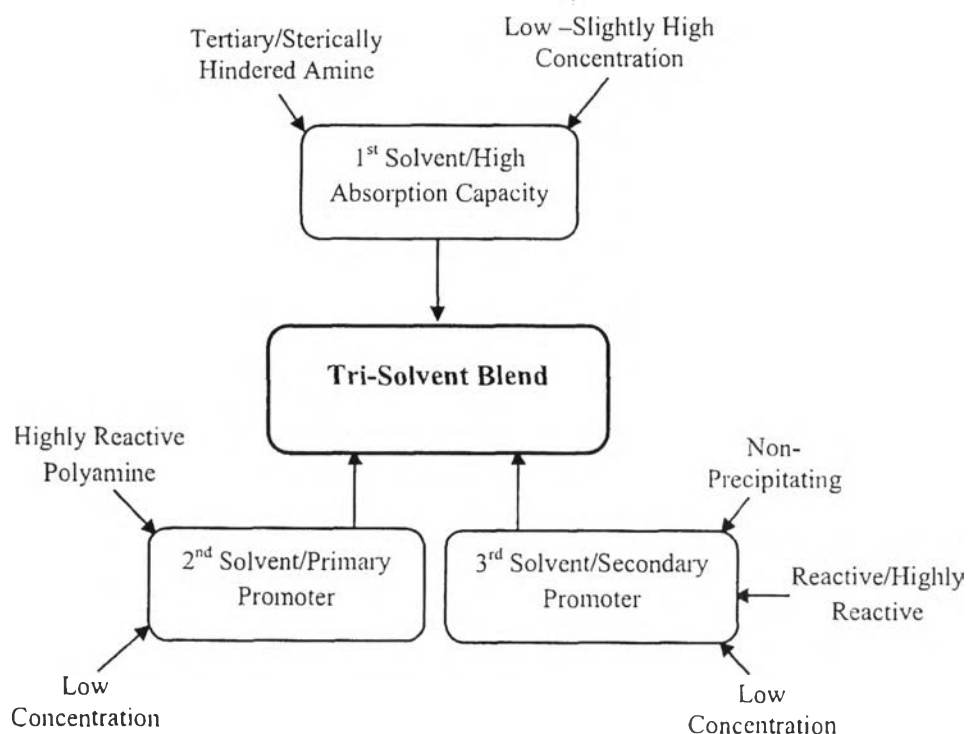
Figure 5.1 Proposed Individual solvent selection and their concentration in tri-solvent blends.

• Based on the experimental findings from this research, for ternary solvent blend (tri-solvent blend) it is integral to first study all the individual solvents to ascertain their maximum concentration without forming solid precipitates (Figure 5.1). From this, the benchmark $H_2O/Amine$ molar ratio can be determined. This will serve as an important parameter while blending three solvents. This is where MEA becomes highly important and special, because it does not precipitate at almost pure state (99 wt% or 16.5 M). For ternary blends involving MEA, only the high absorption capacity and primary promoter solvents will need to be studied in order to determine their $H_2O/Amine$ molar ratio.

- The validated ProMax 3.2 simulation was to predict possible energy penalties of the ternary blends compared to 5 M MEA. The simulation results indicated that the ternary blends with concentrations above 5 M all had lower reboiler duty (5.3 – 26.3 %) than 5 M MEA. Though it will not be regarded as the true energy reductions, but can serve as a pre-information.

- It was also noticed from the simulation results that ProMax 3.2 was not able to predict the actual equilibrium CO_2 loading of most of the ternary blends. This can be noticed while comparing CO_2 loadings from the simulation (15 % CO_2) and experimental results in Figure 4.9 (100 % CO_2).

The conclusion as highlighted above can also serve as a guide in making proper selection of each solvent concentration in the ternary blend (Figure 5.1). The other huge advantage of this blend is that the individual solvents are all well studied, known and commercially available. More analysis of different concentrations of the AMP – PZ – MEA ternary blend needs to be studied for better understanding.

5.2 Recommendations

Recommendations for future research investigation are as follows;

- Study the viscosity, reactivity and net cyclic capacity, desorption rate, regeneration energy of all concentrations of the AMP – PZ – MEA ternary blends compared to both 5 M MEA and 3 M AMP – 1.5 M PZ binary blend.

- The carbamate and bicarbonate concentrations of the rich AMP – PZ – MEA solutions should be studied. This will give proper idea on the dominant reactions that take place (AMP – CO_2, PZ – CO_2 or MEA – CO_2) during the capture of CO_2.

- Other high capacity amines like tertiary or sterically hindered amines (1 mol CO_2/ mol amine) which are also less viscous (at same molar concentration as AMP) can be used in the ternary blend in place of AMP. This can allow the use of higher concentrations of the ternary blend.

- For the primary promoters, PZ can be interchanged with other polyamines (that are very soluble in water and less viscous) to monitor possible increase in both equilibrium CO_2 loading and absorption working capacity. Other polyamines could allow its higher concentrations.

- Considering the secondary promoter (MEA), there's no amine available that have its special quality of being both reactive and non-precipitation at 16.5 M (99 wt%). More amine synthesis can be done to develop new solvents with similar special property. This will allow the secondary promoter to be used as high as 4 M in the ternary blend without triggering precipitation.

- The potential of applying ternary solvent blends can also lead to the application of quaternary solvent blends. Appendix J highlighted possible quaternary solvent blends for CO_2 capture, where AMP – PZ – MEA was further promoted by diethylenetriamine (DETA).