CHAPTER 4

RESULTS AND DISCUSSION

4.1 Studies of single viscosity index improver

4.1.1 The ability to increase viscosity index

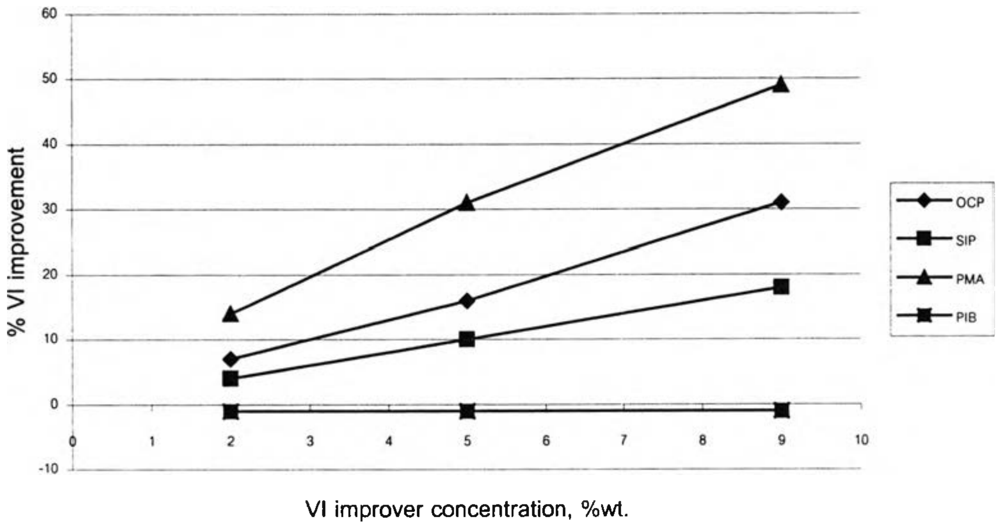

Figure 4.1 VI improvement of mineral base oil containing OCP, SIP, PMA and PIB

From Table A1 and Figure 4.1, polymethacrylate (PMA) is the best viscosity index improver follow by olefin copolymer (OCP), styrene-diisoprene copolymer (SIP) and polyisobutylene (PIB), respectively. These abilities were not so significantly different at low concentration but prevailed at higher concentration.

The ability of an increase in Viscosity Index of each VI improver is depended on the polymer's molecular size. The VI improver with large molecular size also has higher molecular weight and more surface area to contact with blended oil molecules when the molecule expands. The larger the polymer molecules, the more the contact area. Hence, larger polymer molecules increase viscosity index by interruption the flow of the blended oil better than smaller ones.

At high temperature the loss of viscosity of mineral base oil is compensated by the expansion of VI improver molecules. Results in this study were found to follow the theory stated above.

4.1.2 The thickening efficiency

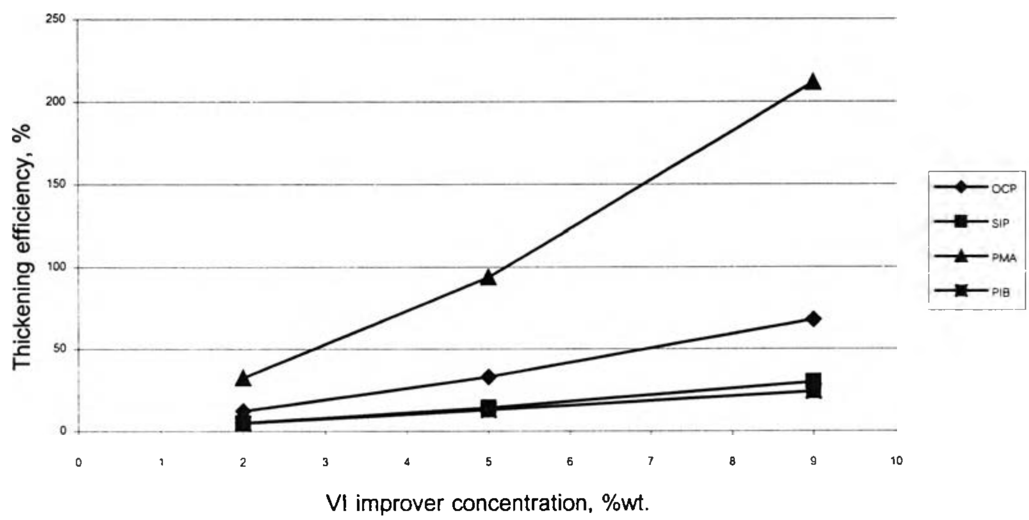

Figure 4.2 Thickening efficiency of mineral base oil containing OCP, SIP, PMA and PIB

The thickening efficiency was measured by comparing the viscosity of mineral base oil with test samples (Mineral base oil + VI improver). The differentiation indicates the thickening efficiency of the test samples. Table A1 and Figure 4.2 show that the thickening efficiency of VI improver. PMA had the highest thickening efficiency following by OCP, SIP and PIB respectively. From the experiment, thickening efficiency was found to be depended on molecular structure and weight percentage of carbon backbone in polymer molecules, and not just the molecular weight of the molecules. For the VI improver of the same type, the molecular weight decides the thickening efficiency, for example, PMA with high molecular weight has a better thickening efficiency than PMA with low molecular weight. The experiment results in Table 4.1 shows the % molecular weight of carbon backbone and approximated molecular weight of the VI improver.

Table 4.1 Percentage of molecular weight in backbone [4]

VI improver Type	%MW in backbone	Appx. molecular weight
Olefin copolymer	79	125,000
Polyisobutylene	48	910
Hydrogenated Styrene-isoprene copolymer	47	110000
Polymethacrylate	26	550000

From Table 4.1, the thickening efficiency of PMA is higher than that of other VI improvers due to its higher molecular weight while PIB gave a very poor thickening efficiency because it has low molecular weight.

4.1.3 Viscosity at low temperature

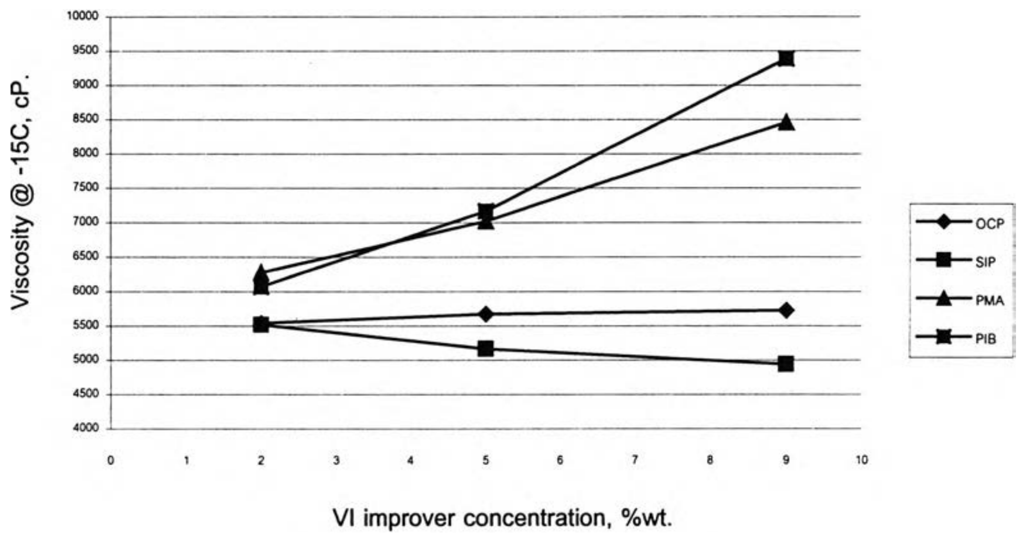

Figure 4.3 Viscosity at -15°C of mineral base oil containing OCP, SIP, PMA and PIB

From Table A1 and Figure 4.3, when using a single VI improver, viscosities at -15°C of blended oil increase with an increase of the concentration of OCP, PMA, and PIB, while decrease with a decrease of the SIP concentration. This can be explained that SIP has star shaped structure which could be fold to globular structure, therefore viscosity is decreased.

4.2 Studies of dual viscosity index improver systems

In this study, the mineral base oil was blended with dual VI improver system, without other additive.

4.2.1 VI improvement

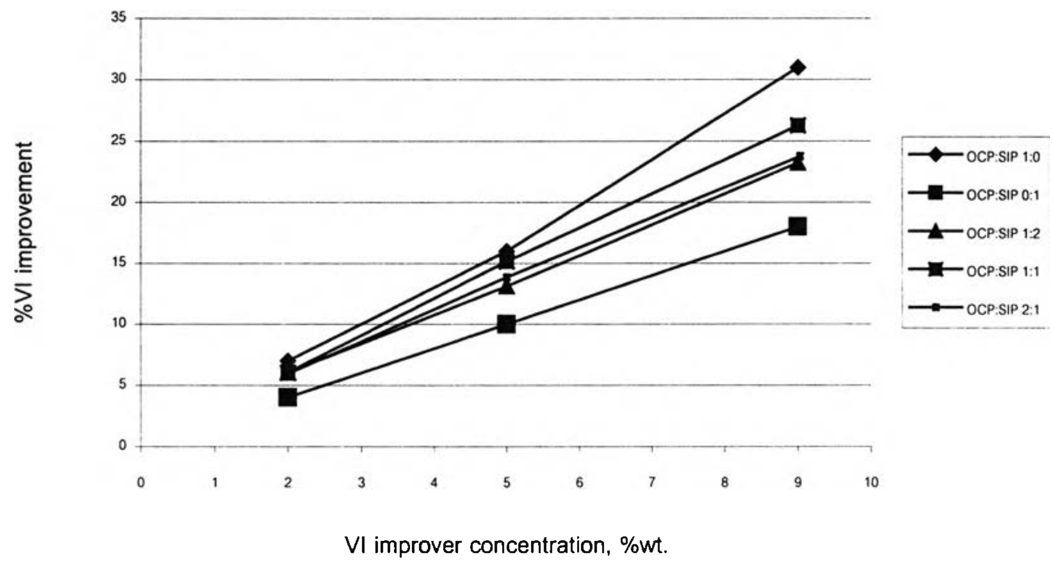

Figure 4.4a VI improvement of mineral base oil containing OCP, SIP, and OCP-SIP systems.

Figure 4.4a shows VI improvement of mineral base oil containing dual OCP-SIP viscosity index improvers. The viscosity indexes of the blended oil increase when the concentration of the viscosity index improvers increase. The improvements are more significant when the concentration of OCP is high. This indicates that, molecules of OCP, which are longer in length, can interrupt the flow of the blended oil molecules better than the star shape SIP molecules.

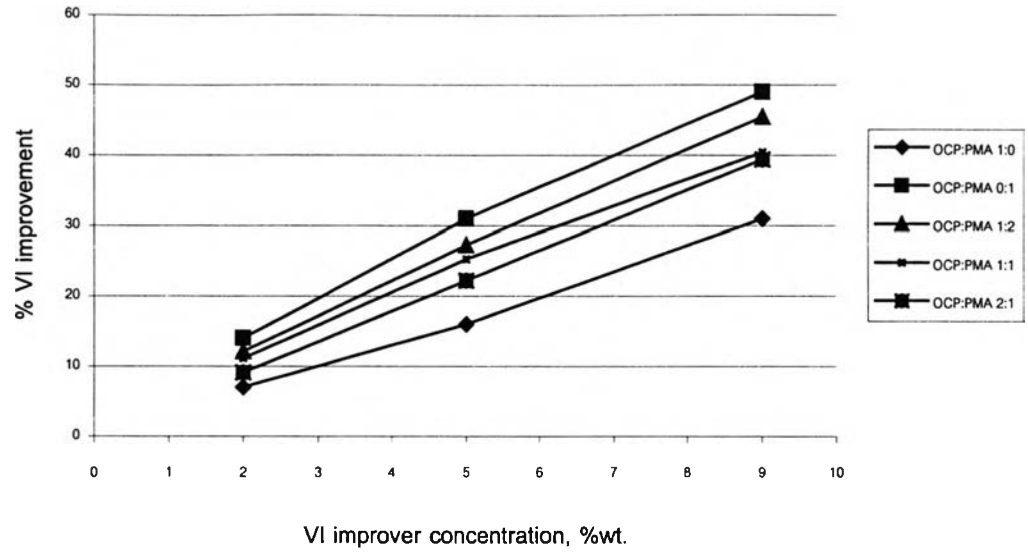

Figure 4.4b VI improvement of mineral base oil containing OCP, PMA, and OCP-PMA systems

Figure 4.4b illustrates the improvements of the blended oil by adding the dual OCP-PMA viscosity index improvers. The viscosity indexes of the blended oil increase when the overall concentration of the viscosity index improvers increase. From the graph above, PMA significantly better increase the viscosities of the blended oil than OCP. This is because PMA molecules are bigger and longer than OCP molecules.

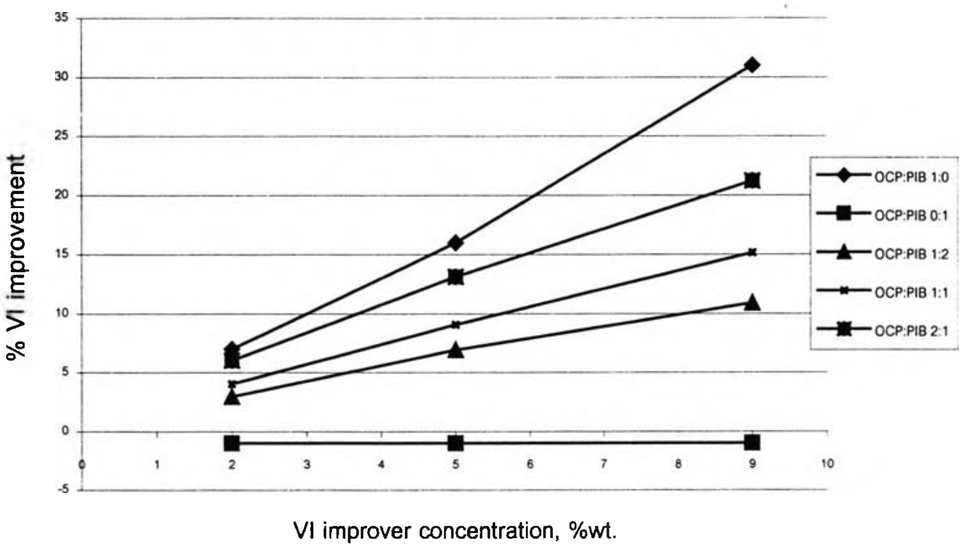

Figure 4.4c VI improvement of mineral base oil containing OCP, PIB and OCP-PIB systems

Figure 4.4c shows VI improvement of the dual OCP-PIB viscosity index improvers in blended base oil. The viscosity indexes of the blended oil containing OCP increase when its ratios in blended oil increase. PIB represented with a square line stays parallel with the concentration axis. This means PIB does not improve the viscosity index of the blended oil.

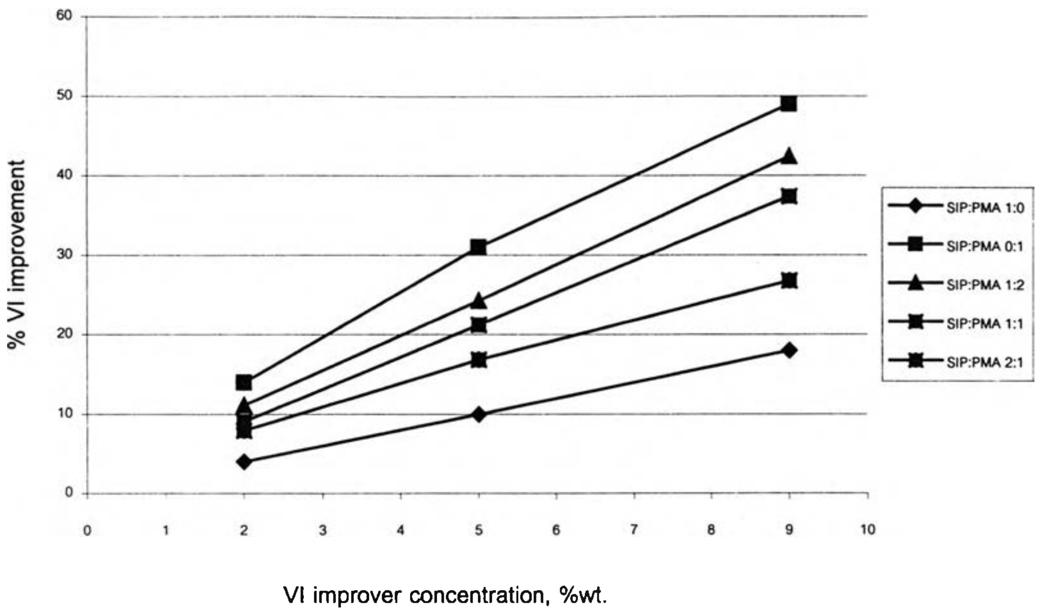

Figure 4.4d VI improvement of mineral base oil containing SIP, PMA and SIP-PMA systems

From Table A2 and Figure 4.13, VI improvements of the blended oil are affected by the overall concentration of the dual PMA-SIP viscosity index improvers. Increasing the concentration of either SIP or PMA will increase the viscosity index improvement of the blended oil. PMA is however more effective viscosity index improve than SIP as can be seen from the graph. The size and shape of PMA molecules are large and thus expand more than SIP molecules when subjected to heat.

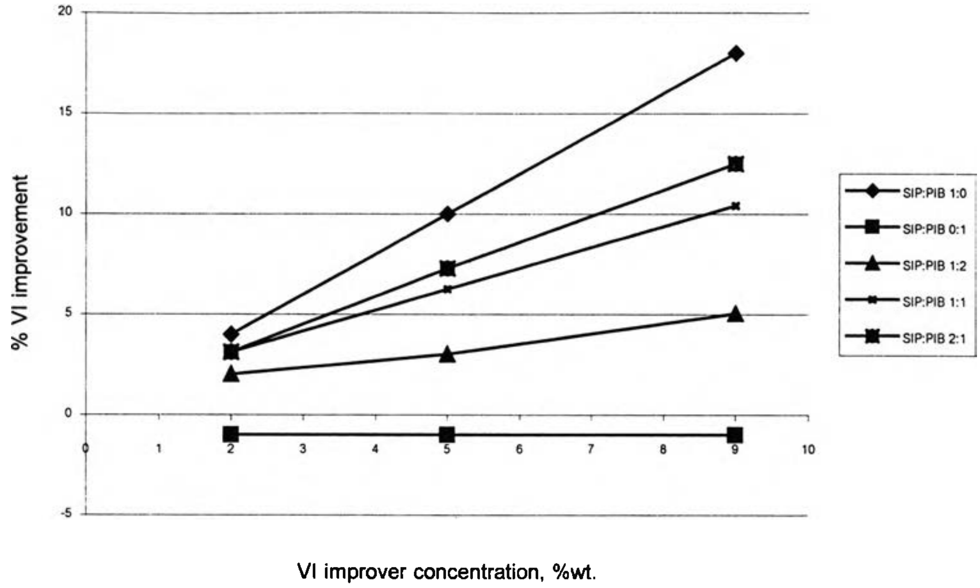

Figure 4.4e VI improvement of mineral base oil containing SIP, PIB and SIP-PIB systems

Figure 4.4e shows that the total concentrations of SIP affect viscosity index values of the blended oil. Increasing the concentration of SIP in the blended oil increases the percentage of improvements while increasing PIB contents does not change the system overall improvements.

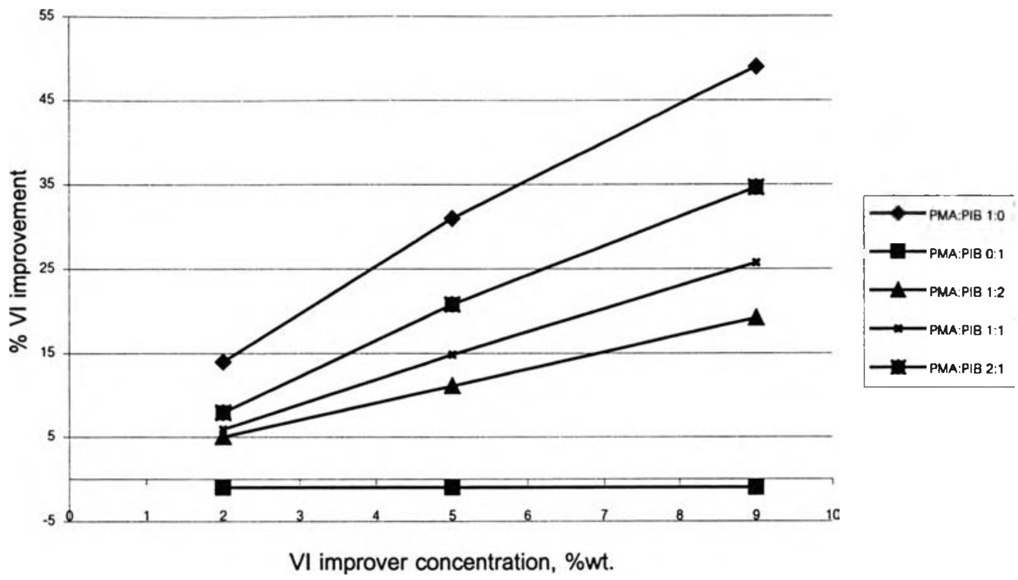

Figure 4.4f VI improvement of mineral base oil containing PMA, PIB and PMA-PIB systems

Figure 4.4f and Table A2 illustrate VI improvements of mineral base oil containing dual PMA-PIB viscosity index improver. PMA containing larger polymer molecules dominated the properties of the blended oil. The orders of the improvements are as follows: single PMA, dual PMA-PIB system with ratio 2:1, 1:1, 1:2, and single PIB. It should be noticed that, PIB is a poor VI improver as shown in the graph, it hardly improve the viscosity index values of the blended oil.

4.2.2 Thickening efficiency

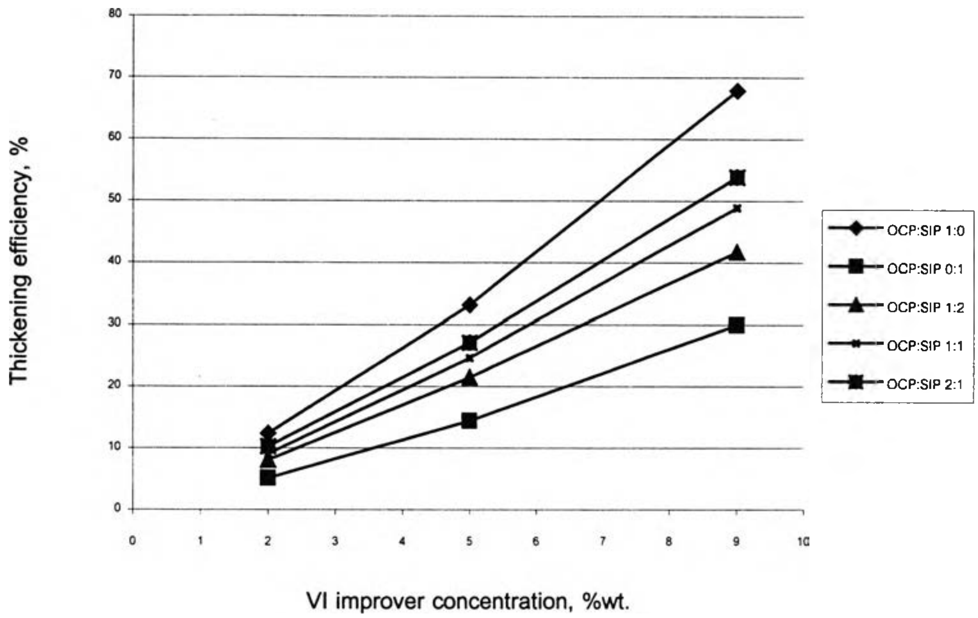

Figure 4.5a Thickening efficiency of mineral base oil containing OCP, SIP, and OCP-SIP systems

Table A2 and Figure 4.5a shown the thickening efficiency of the dual OCP-SIP VI improver in blended oil. The results suggested that the thickening efficiencies values increase when the overall concentration of viscosity index improvers increase. In blended oil with dual OCP-SIP viscosity index improver, OCP effectively increases the thickening efficiencies of the blended oil while SIP provided less improvement. The star shape molecules of SIP restricted its from doing so. It should also be noticed that, even though SIP has higher molecular weight than OCP, it actually has a small size than OCP. The branches cause the molecules to be heavy but small.

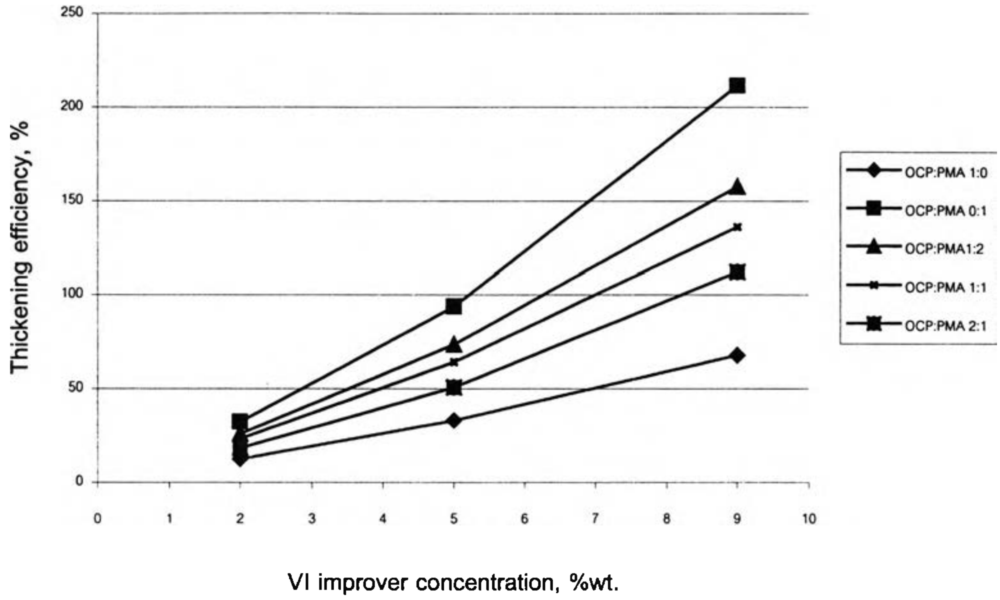

Figure 4.5b Thickening efficiency of mineral base oil containing OCP, PMA, and OCP-PMA systems

As shown in Table A2 and Figure 4.5b, the thickening efficiencies of the dual OCP-PMA system at various ratios are in between the thickening efficiency of the two single VII as predicted. The thickening efficiencies of the graph increase when the total concentration of the viscosity index improver increases. As mentioned earlier, the thickening efficiency of the system is depended on the molecular weight of viscosity index improver used. PMA possess higher molecular weight than OCP thus influences the thickening efficiency of the blended oil more than OCP.

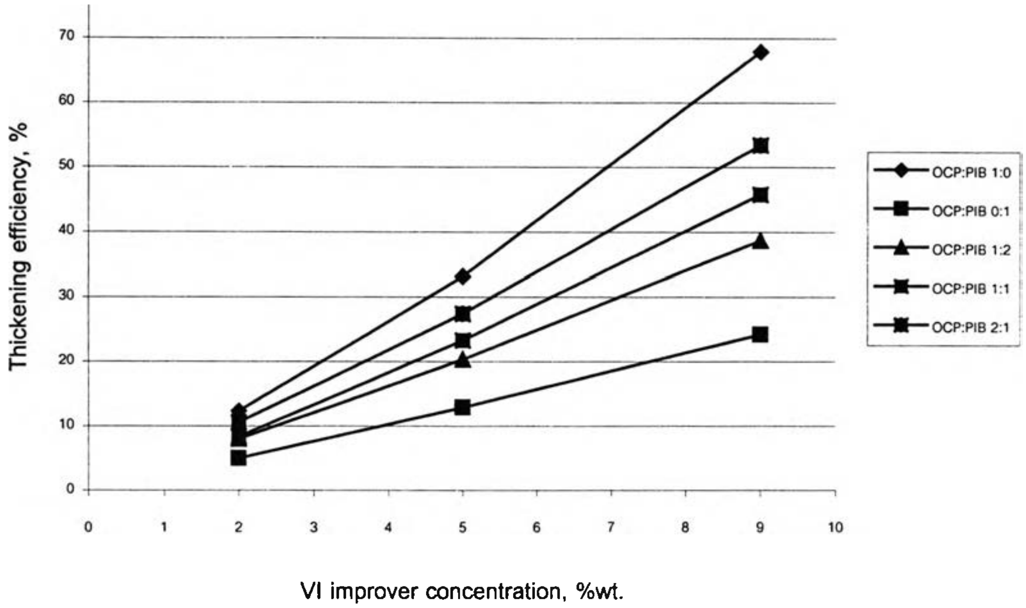

Figure 4.5c Thickening efficiency of mineral base oil containing OCP, PIB, and OCP-PIB systems

Figure 4.5c, shows the thickening efficiencies of the dual OCP-PIB system. The results show that, increasing the concentration of the viscosity index improvers increases the thickening efficiency of the blended oil. The thickening efficiencies at various ratios are closer to the thickening efficiency of OCP. PIB has an extremely low molecular weight, thus, the chains are short and tiny, and so, provided poor thickening improvement. In fact, PIB is by far the poorest thickening efficiency improver in this study.

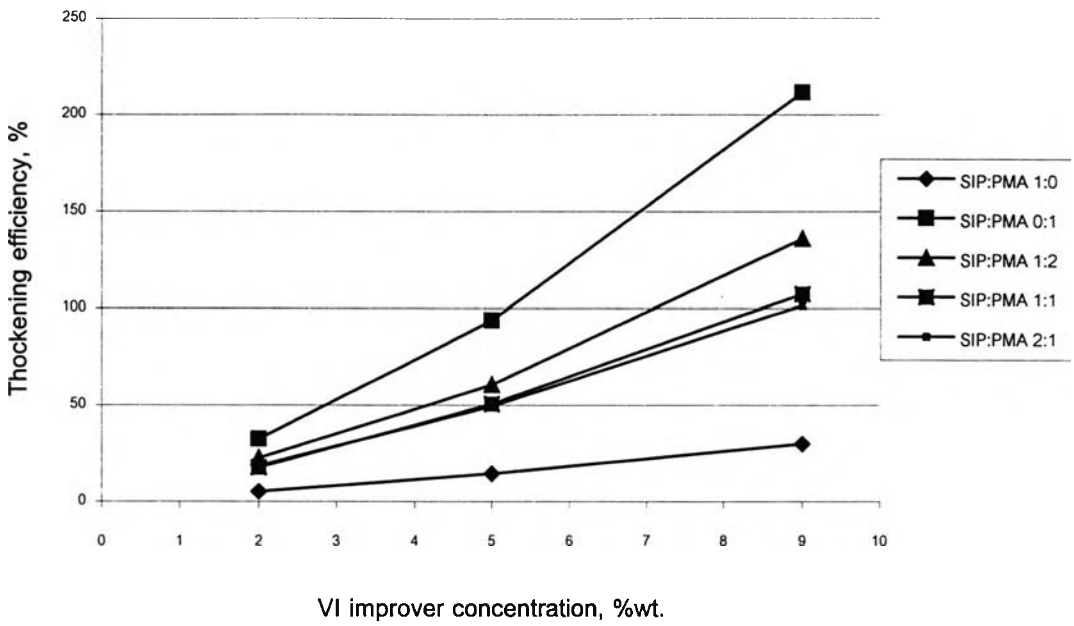

Figure 4.5d Thickening efficiency of mineral base oil containing SIP, PMA, and SIP-PMA systems

From Figure 4.5d, the thickening efficiency of SIP and PMA system is significantly different. The results show that thickening efficiency of the dual SIP-PMA system is influenced by the ratios of PMA in blended oil. This can be explained as PMA molecular size is much larger than SIP, thus, when subject to heat, PMA molecules will stretch more than SIP molecules and consequently interrupted the normal flow of the blended oil more than SIP.

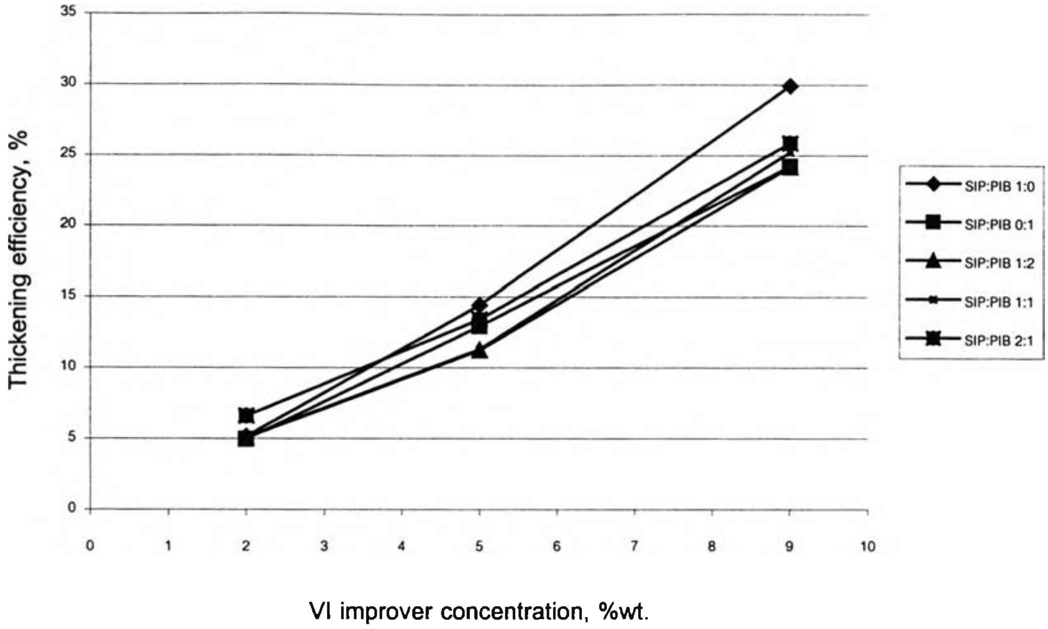

Figure 4.5e Thickening efficiency of mineral base oil containing SIP, PIB, and SIP-PIB systems

From Figure 4.5e, the thickening efficiency of SIP-PIB system is insignificantly different. At various ratios, the thickening efficiencies of the dual blended oils neither rest on single PIB nor single SIP side but stay rather in the middle. The clustering of the graph is caused by the single thickening efficiency values, which are insignificantly different (viscosity at 100°C less than reproducibility value (reference to ASTM D445) or about 0.76% $\overline{X}$).

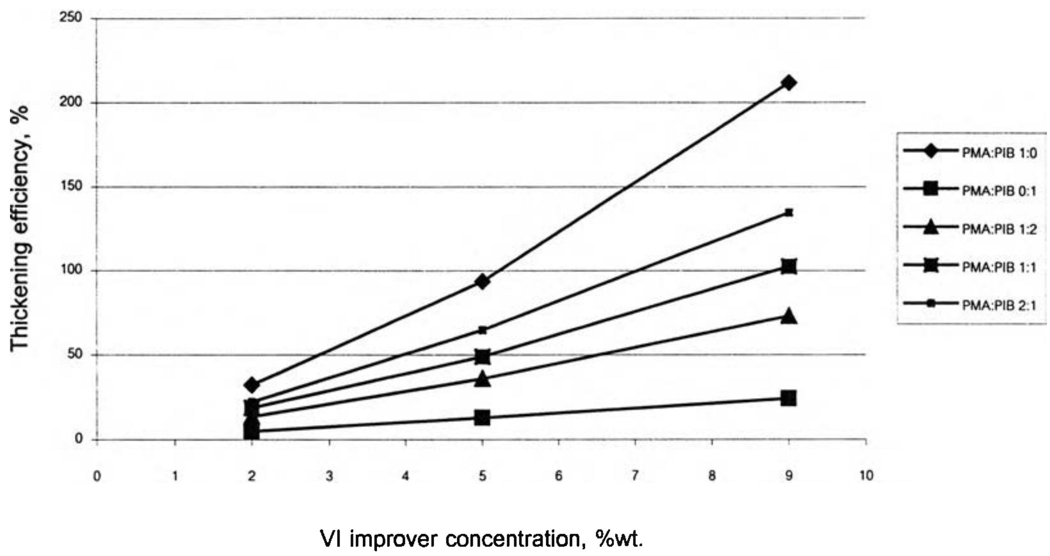

Figure 4.5f Thickening efficiency of mineral base oil containing PMA, PIB, and PMA-PIB systems

Figure 4.5f illustrates the thickening efficiency of blended oils at various concentrations. An increase in concentration of PMA-PIB resulted in an increase in thickening efficiency of blended oils. The thickening efficiencies of the dual PMA-PIB blended align between the two single blended oils. The graph indicates that thickening efficiency of the PMA-PIB system is optimized by the present of the large molecules of PMA.

4.2.3 Viscosity at low temperature (CCS@ -15°C)

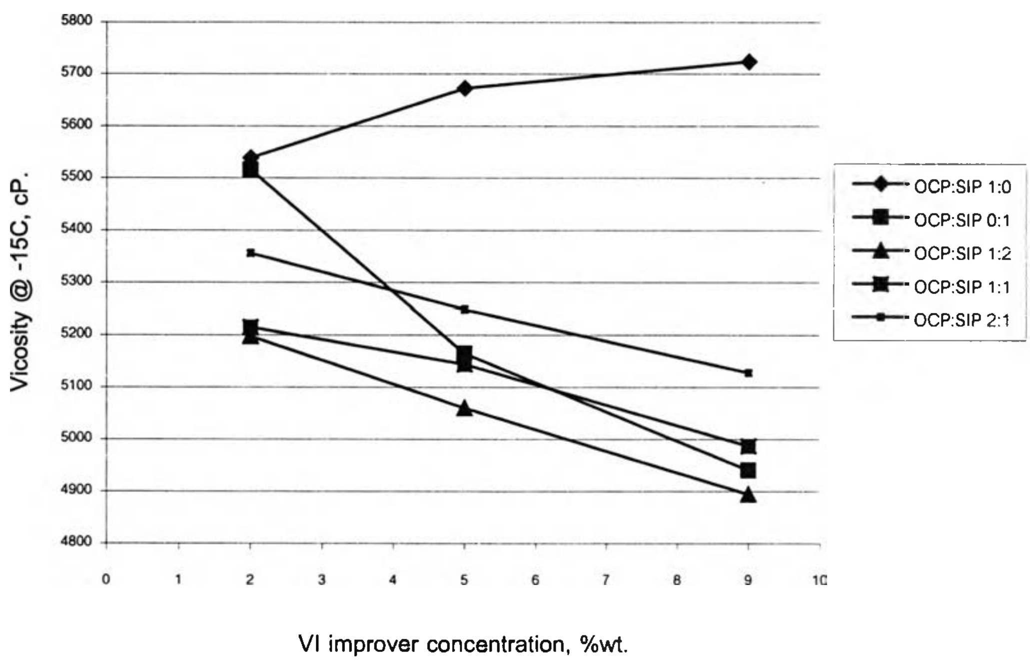

Figure 4.6a Viscosity at -15°C of mineral base oil containing OCP, SIP, and OCP-SIP systems

From Figure 4.6a, when using dual OCP-SIP VI improvers, the viscosity values of blended oil at total concentration of 2% VI improver are significantly different. An increase of the total concentration of OCP-SIP resulted in a decrease in viscosity of blended oils due to the effect of SIP as previously mentioned.

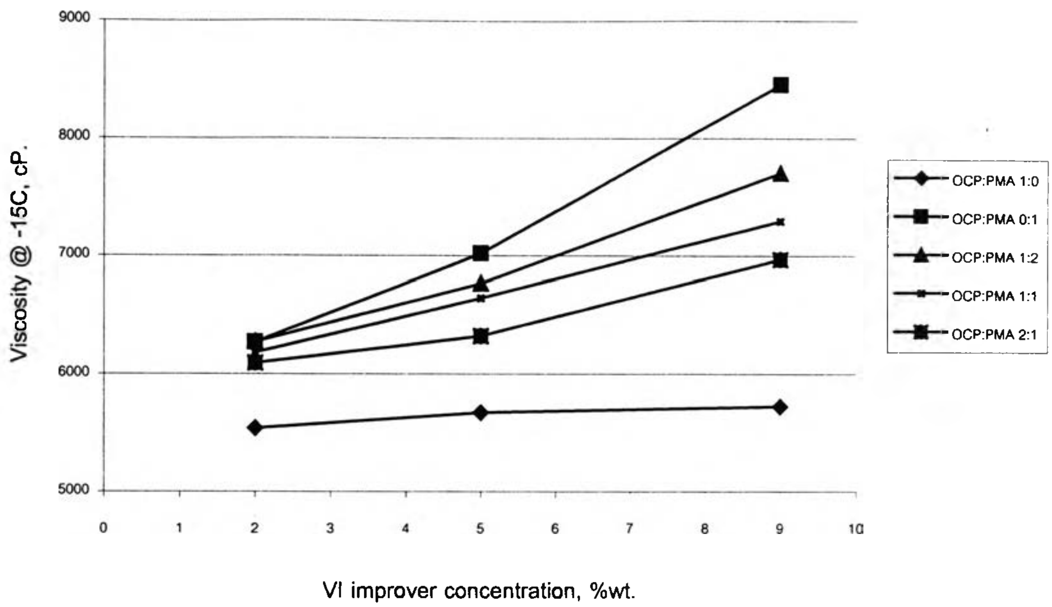

Figure 4.6b Viscosity at -15°C of mineral base oil containing OCP,PMA, and OCP-PMA systems

From Figure 4.6a, when dual PMA-OCP VI improvers at the concentration ratios of 1:2, 1:1 and 2:1, the viscosity of blended oils was found to be increased with an increase of total concentration of VI improver. It is noted that a change in viscosity of blended oil is affected by the concentration of PMA in PMA-OCP system. This can be explained as; the sizes of PMA molecules are much bigger than those of OCP, thus, PMA molecules more likely interrupt the flow of the blended oil.

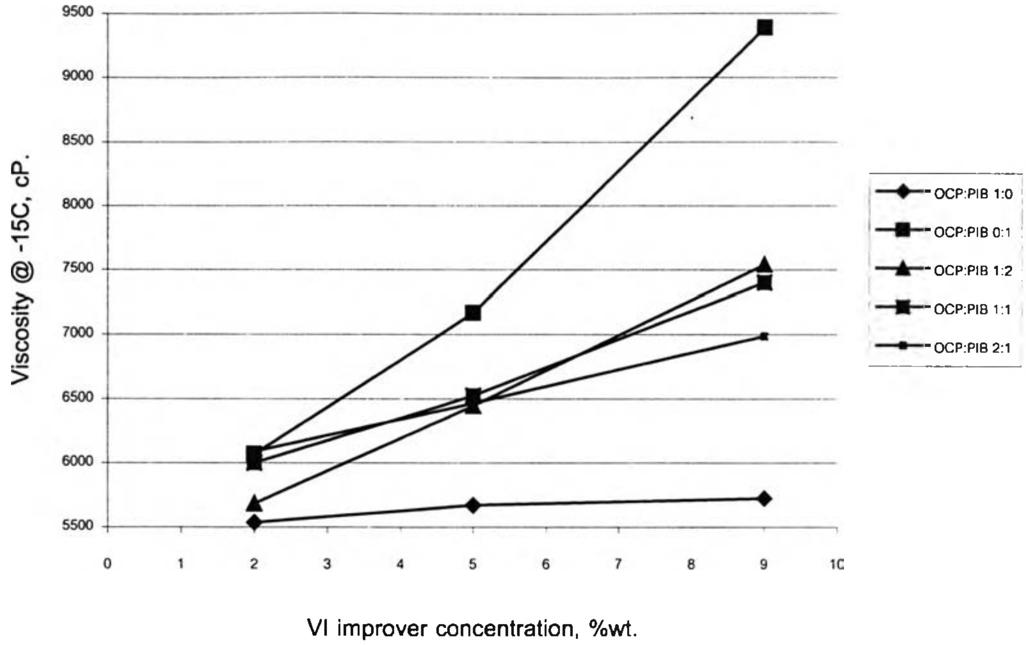

Figure 4.6c Viscosity at -15°C of mineral base oil containing OCP,PIB, and OCP-PIB systems

From Figure 4.6c, when dual OCP-PIB VI improvers at the concentration ratios of 1:2, 1:1 and 2:1 were used, the viscosity of blended oils was found to be increased with an increase of total concentration of VI improver. Also, it should be noticed that the concentration ratios of OCP and PIB changed the viscosity of blended oil which was dominantly affected by the concentration of PIB. The phenomenon can be explained by the extrapolation of PIB, which has a much lower VI and thus has a high viscosity at low temperature.

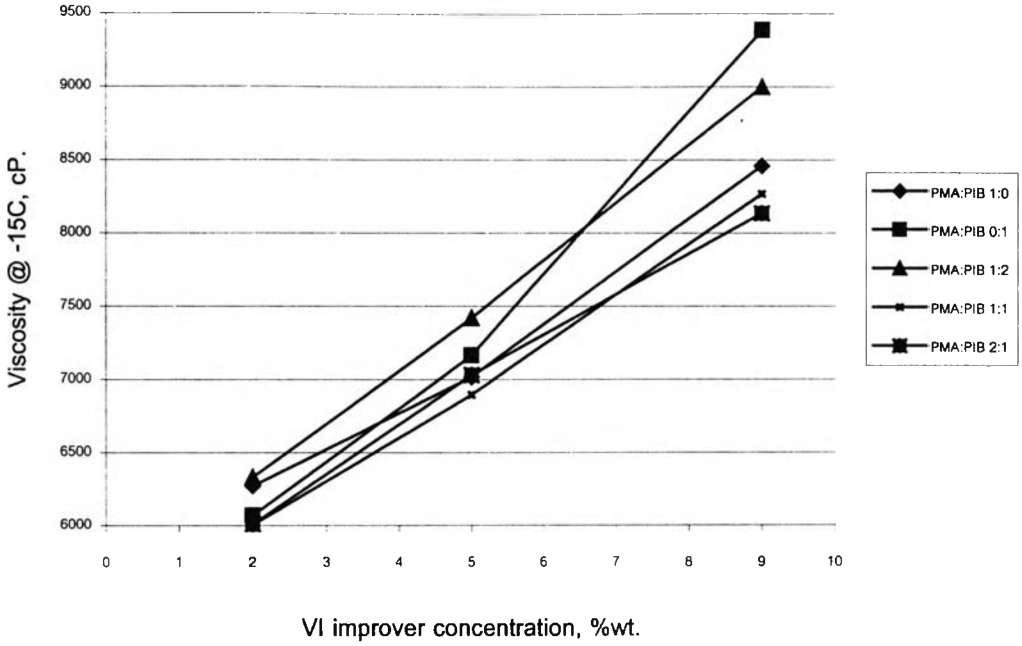

Figure 4.6d Viscosity at -15°C of mineral base oil containing PMA,PIB, and PMA-PIB systems

From Figure 4.6c, at the constant total concentration of PMA and PIB, viscosities of blended oil at different concentration ratios of PMA and PIB were insignificantly different because of similar viscosity of blended oil containing single VI improver of PMA or PIB. An increase in the total concentration of the total concentration of VI improver resulted in an increase in viscosity of blending oil.

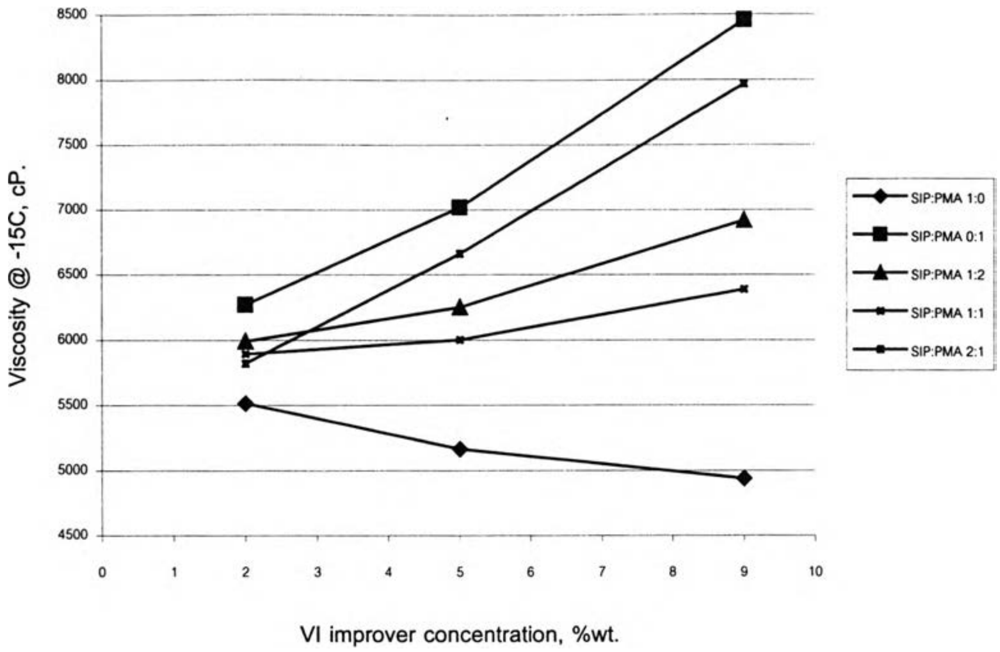

Figure 4.6e Viscosity at -15°C of mineral base oil containing SIP,PMA, and SIP-PMA systems

From Figure 4.6e, when dual SIP-PMA VI improvers at the concentration ratios of 1:2, 1:1 and 2:1 were used, the viscosity of blended oils was found to be increased with an increase of the total concentration of VI improvers. It is noted that an increase in a single SIP results is decreased in viscosity. Results indicated that at the concentration ratios of SIP-PMA used in this study, a change in viscosity of blended oil is affected by PMA. This is because an increase of VI of base oil containing PMA is greater than a decrease of VI of base oil containing SIP.

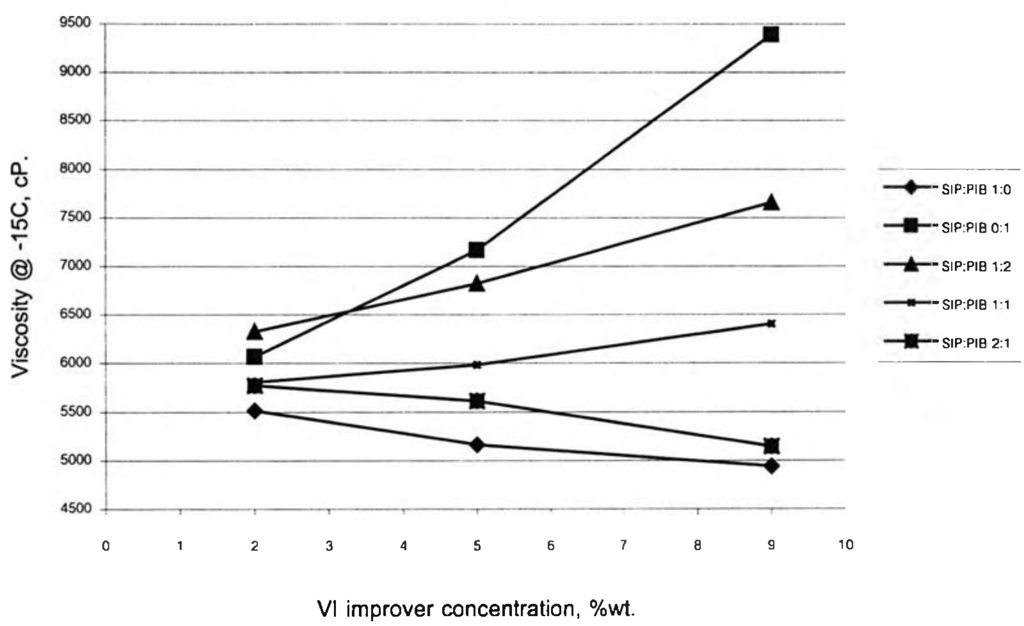

Figure 4.6f Viscosity at -15°C of mineral base oil containing SIP,PIB, and SIP-PIB systems

From Figure 4.6f, when using dual SIP-PIB VI improvers at the concentration ratio of 2:1, viscosities of blended oils decrease with an increase of the total concentration of VI improver. However, at the concentration ratios of 1:1 and 1:2 SIP:PIB, viscosities of blended oils increase when the total concentration of VI improvers increases. This indicates that when the amount of SIP is greater than that of PIB, a change of viscosity of blended oil is depended on SIP.

4.3 Selection of VI improver system for fully engine oil formulation

Based on the results of VI improver systems in section 4.2, the following ratios of each system were selected to produce SAE 20w50 multi-grade engine oil.

Table 4.2 Selected VI improver system.

VI improver system	Ratio	Cause
OCP -SIP	1 :1	Maximum VI improvement
		Minimun CCS
OCP -PMA	2 :1	Minimum CCS
		Minimum cost
OCP -PIB	2 :1	Maximum VI improvement
		Maximum Thickening effect
		Minimum CCS
SIP -PMA	1 :2	Maximum VI improvement
		Maximum Thickening effect
SIP -PIB	1 :1	Maximum VI improvement
		Minimum CCS
PMA -PIB	1 :2	Minimum cost

4.4 The suitability of VI improver system for production of SAE 20W50 multi-grade engine oil regarding cost of production and lubricant efficiencies.

Table A4 shows the results when attempted to formulate API SJ/CF SAE 20W50 multi-grade engine oil based on the specification of SAEJ 300. The properties of engine oils containing single VI improver and dual was compared. Table

A4 shows the cost of production and quantities of raw material used, calculated based on the cost of raw materials supplied by domestic suppliers.

From Table A4, PIB alone is not recommended to be used to produce SAE 20W50 multi-grade engine oil. The specification of SAE 20W50 specified CCS maximum of 9500 cP. while the attempt to formulate the engine oil using PIB alone yielded best CCS of 10569 cP. Several adjustments were made but failed to achieve the required specification.

For all systems, shear stability and viscosity at high temperature and high shear rate experiment were conducted on dual VI improver system to ensure that all systems were on specification. The results are shown in table A5. All systems were on specification for the experiments.

Disregarding the cost, SIP at 15 W% content was found to be the best VI improver for producing the multi-grade engine oil. SIP at 15 W% yielded optimum viscosity at low temperature (CCS) and VI and reasonable viscosity at 100°C were found to be in comparison with other VI improvers.

Out of the 6 selected VI improver systems, four VI improver systems capable for producing SAE 20W50 multi-grade engine oil. These are; OCP-SIP (1:1 ratio), OCP-PMA (2:1 ratio), OCP-PIB (2:1 ratio) and SIP-PMA(1:2 ratio). SIP-PIB (1:1) and PMA-PIB (1:2) were found to be off specification with exceeded a CCS value. Several adjustments were attempted but failed to achieve the required specification.

The viscosity of the four on specification systems are similar while different in their Permanent viscosity loss (PVL). OCP-PMA and SIP-PMA systems have higher PVL than OCP-SIP and OCP-PIB systems.

Taking cost into consideration, OCP-PIB system gives a highest potential to be used in industry as it has a reasonable property and low cost.