REFERENCES

Bilderback, C.A., and McDougall, L.A. (1969). Complete paraffin control in petroleum production. Journal of Petroleum Technology, 1151-1156.

Burger, E.D., Perkins, T.K., and Striegler, J.H. (1981). Studies of wax deposition in Trans Alaska pipeline. Journal of Petroleum Technology, 1075-1086.

Carnahan, N.F. (1989). Paraffin deposition in petroleum production. Journal of Petroleum Technology, 41(10), 1024-1025.

Chen, J., Zhang, J., and Li, H. (2004). Determining the wax content of crude oils by using differential scanning calorimetry. Thermochimica Acta, 410, 23-26

Chevallier, V., Bouroukba, M., Petitjean, D., Dirand, M., Pauly, J., Daridon, J.L., and Ruffier-Meray, V. (2000). Crystallization of a multiparaffinic wax in normal tetradecane. Fuel, 79, 1743-1750.

Elsharkawy, A.M., Al-Sahhaf, T.A., and Fahim, M.A. (2000). Wax deposition from Middle East crudes. Fuel, 79, 1047-1055.

Faust, H.R. (1978). The thermal analysis of waxes and petrolatums Thermochimica Acta, 26, 383-398

García, M.D.C. (2000). Crude oil wax crystallization. The effect of heavy n-paraffins and flocculated asphaltenes. Energy & Fuels, 14, 1043-1048.

García, M.D.C., Carbognani, L., and Urbina, M. (2000). The influence of alkane class-types on crude oil wax crystallization and inhibitors efficiency. Journal of Petroleum Science and Engineering, 25, 99-105.

Groffe, D., Groffe, P., Takhar, S., Andersen, S.I., Stenby, E.H., Lindeloff, N., and Lundgren, M. (2001). A wax inhibition solution to problematic fields: a chemical remediation process. Petroleum Science and Technology, 19(1&2), 205-217.

http://en.wikipedia.org/wiki/solvent "Solvent-Wikipedia, the free encyclopedia"

Li, M., Su, J., Wu, Z., Yang, Y., and Ji, S. (1997). Study of the mechanism of wax prevention in a pipeline with glass inner layer. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 123-124, 635-649.

Machado, A.L.C., Lucas, E.F., and González, G. (2001). Poly(ethylene-co-vinyl acetate) (EVA) as wax inhibitor of a Brazilian crude oil: oil viscosity, pour

point and phase behavior of organic solutions. Journal of Petroleum Science and Engineering, 32, 159-165.

Malikhow, K. (2006) Study of wax inhibitor and their stabilities for Thai crude oil. MS thesis; The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

Mansoori, G.A. (2001). Heavy organic deposition and fouling in petroleum fluids. Available from http://uic.edu/~mansoori/HOD_html.

Marques, L.C.C., Machado, A.L.C., Garcia, R.L.P., Soldan, A.L., and Campagnili, E.A. (1997). Organic deposition presents challenges in Brazil's off shore fields. World oil, 125-133.

Misra, S., Baruah, S., and Singh, K. (1998). Paraffin problems in crude oil production and transportation: a review. Paper SPE 28181, SPE Production & Facilities, 50-54.

Numura, P. (2005) The influence of wax inhibitors on Thai crude oils. MS thesis; The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

Pedersen, K.S., and Rønningsen, H.P. (2003). Influence of wax inhibitors on wax appearance temperature, pour point, and viscosity of waxy crude oils. Energy & Fuels, 17, 321-328.

Quintella, C.M., Musse, A.P., Castro, M.T.P.O., Scaiano, J.C., Mikelsons, L., and Watanabe, Y.N. (2006). Polymeric surfaces for heavy oil pipelines to inhibit wax deposition: PP,EVA28, and HDPE. Energy & Fuels, 20, 620-624.

Rønningsen, H.P., Bjørndal, B., Hansen, A.B., and Pedersen, W.B. (1991). Wax precipitation from North Sea crude oils. 1. crystallization and dissolution temperatures, and Newtonian and Non-Newtonian flow properties. Energy & Fuels, 5, 895-908.

Sawhney, S.S., and Jassal, M.M.S. (1991). Studies on the influence of ester-type chemical additives on wax deposition. Fuel, 70, 1488-1490.

Srisirivilaikul, W. (2004) Evaluation risks of wax deposition for Thai crude oils. MS thesis; The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

Thanh, N.X., Hsieh, M., and Philp, R.P. (1999). Waxes and asphaltenes in crude oils. Organic Geochemistry, 30, 119-132.

Towler, B.F., and Rebbapragada, S. (2004). Mitigation of paraffin wax deposition in cretaceous crude oils of Wyoming. Journal of Petroleum Science and Engineering, 45, 11-19.

Wang, K.S., Wu, C.H., Creek, J.L., Shuler, P.J., and Tang, Y. (2003) Evaluation of effects of selected wax inhibitors on paraffin deposition. Petroleum Science and Technology, 21(3&4), 369-379.

Weingarten, J.S., and Euchner, J.A. (1986) Methods of predicting wax precipitation and deposition. SPE 15654, Presented at 61st Annual Conference of SPE, New Orleans, LA. Oct 5-8.

www.waxindia.com "Welcome to wax India"

Zhang, J., Wu, C., Li, W., Wang, Y., and Han, Z. (2003). Study on performance mechanism of pour point depressants with differential scanning calorimeter and X-ray diffraction methods. Fuel, 82, 1419-1426.

APPENDICES

Appendix A True Boiling Point Curve

Table A1 True boiling point temperature versus recovery percent of Phet crude obtained from sim-dist GC

Recovery (%)	TBP temperature (°C) from Sim-Dist GC data		
	Run 1	Run 2	Average
0	67.8	69.6	68.7
5	59.0	62.4	60.7
10	90.1	95.0	92.6
20	137.5	144.6	141.1
30	170.6	179.9	175.3
50	230.8	243.2	237.0
70	297.0	309.8	303.4
80	321.9	342.1	332.0
90	365.5	391.3	378.4
100	440.8	478.4	459.6

Appendix B Calculation of n-Paraffins Content in Crude Oil

Example: the calculation of the amount of C_5H_{12} containing in Phet crude oil 0.0289 g.

Standard

The certified hydrocarbon solution contains C_5H_{12} 0.1948 wt%

In the standard 1 g, it will contain $C_5H_{12} = (0.1948 \times 1) / 100 = 1.948 \times 10^{-3}$ g

The whole standard solution, 1 g, was dissolved in 25 ml of CS_2.

In 25 ml or 25×10^3 µl of CS_2 solution contained $C_5H_{12} = 1.948 \times 10^{-3}$ g

The standard solution 1 µl injection contained $C_5H_{12} = (1.948 \times 10^{-3} \times 1) / (25 \times 10^3)$

$= 7.792 \times 10^{-8}$ g or 7.792×10^{-2} µg.

From GC chromatogram of the standard, it was found that

C_5H_{12} peak area = 5572.6 units $\equiv 7.792 \times 10^{-2}$ µg.

If C_5H_{12} peak area = 1 unit $\equiv (7.792 \times 10^{-2} \times 1) / (5572.6) \equiv 1.3982 \times 10^{-5}$ µg.

Crude Oil Sample

Crude oil of 0.0289 g was dissolved in CS_2 4.5665×10^3 µl

The crude solution of 1 µl injection is equivalent to

$(0.0289 \text{ g} \times 1 \text{ µl} \times 10^6) / (4.5665 \times 10^3 \text{ µl} \times 1 \text{ g}) = 6.3287$ µg of crude

From the GC chromatogram of Phet crude oil sample solution

C_5H_{12} having peak area of 3774.9 units $\equiv (1.3982 \times 10\text{-}5 \times 3774.9) / 1$

$\equiv 0.0528$ µg

Therefore, in crude oil of 6.3287 µg, it contained $C_5H_{12} = 0.0528$ µg

$= (0.0528 \times 100) / 6.3287 = 0.8343\%$ (wt)

Similar calculations, which were done for other hydrocarbons in Phet crude sample, are summarized in Tables B-1.

Table B-1 The concentration of n-paraffins in Phet crude

Formular	Peak area		wt% of n-paraffins in the standard	n-paraffins in crude oil (wt%)
	Standard	Phet crude		
C_5H_{12}	5572.6	3774.9	0.1948	0.8352
C_6H_{14}	9465.9	7086.5	0.1782	0.8444
C_7H_{16}	8580.1	2398.0	0.1945	0.3441
C_8H_{18}	6895.2	-	0.1982	-
C_9H_{20}	9055.4	-	0.1981	-
$C_{10}H_{22}$	9132.4	-	0.2183	-
$C_{11}H_{24}$	9215.8	1333.0	0.2091	0.1914
$C_{12}H_{26}$	8179.7	7507.2	0.2127	1.2356
$C_{13}H_{28}$	7974.8	6450.3	0.2126	1.0884
$C_{14}H_{30}$	8271.3	1555.5	0.2226	0.2650
$C_{15}H_{32}$	8205.2	5237.4	0.2263	0.9143
$C_{16}H_{34}$	8070.6	4951.3	0.2213	0.8593
$C_{17}H_{36}$	6934.1	4625.2	0.2322	0.9803
$C_{18}H_{38}$	7123.4	3774.1	0.2203	0.7388
$C_{20}H_{42}$	6633.0	3466.0	0.2205	0.7293
$C_{22}H_{44}$	5759.9	2804.4	0.1984	0.6114
$C_{24}H_{50}$	4607.2	1993.2	0.2297	0.6290
$C_{28}H_{58}$	3506.8	-	0.2236	-
$C_{32}H_{66}$	2831.0	-	0.2043	-
$C_{36}H_{74}$	2632.6	-	0.2147	-
$C_{40}H_{82}$	2613.2	-	0.2108	-
$C_{44}H_{90}$	1995.3	-	0.2049	-
Total				10.2665

Appendix C Effect of Poly(ethylene-co-vinyl acetate) on Pour Point Temperature

Table C1 Pour point temperature of Phet crude when added EVA with 25% vinyl acetate content

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	Pour point (°C)	Average pour point (°C)	SD of pour point (°C)
100	1	0.0025	25.7081	23.5	22.8	0.76
	2	0.0027	26.8632	22.0		
	3	0.0025	25.5202	23.0		
200	1	0.0049	24.6371	20.0	20.7	0.58
	2	0.0049	24.4884	21.0		
	3	0.0046	25.2063	21.0		
400	1	0.0102	25.7454	21.0	20.3	0.58
	2	0.0098	24.6839	20.0		
	3	0.0099	24.7037	20.0		
600	1	0.0148	24.8686	19.5	20.0	0.50
	2	0.0152	25.0196	20.0		
	3	0.0138	23.1594	20.5		
800	1	0.0201	25.2630	26.0	24.7	1.53
	2	0.0204	25.8650	23.0		
	3	0.0194	24.3809	25.0		
1000	1	0.0259	25.8933	25.0	24.7	0.58
	2	0.0261	26.1743	24.0		
	3	0.0253	25.3799	25.0		

Table C2 Pour point temperature of Phet crude when added EVA with 33% vinyl acetate content

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	Pour point (°C)	Average pour point (°C)	SD of pour point (°C)
100	1	0.0032	31.6772	29.5	27.3	1.89
	2	0.0025	25.1073	26.0		
	3	0.0022	21.9571	26.5		
200	1	0.0050	24.8535	24.5	24.7	0.29
	2	0.0049	24.4991	25.0		
	3	0.0049	24.3458	24.5		
400	1	0.0099	24.9781	22.0	21.8	0.29
	2	0.0102	25.7667	21.5		
	3	0.0103	25.7558	22.0		
600	1	0.0153	25.9930	21.0	21.0	1.00
	2	0.0153	25.5619	22.0		
	3	0.0151	25.1427	20.0		
800	1	0.0190	23.8927	24.0	22.0	2.65
	2	0.0202	25.3221	19.0		
	3	0.0195	24.5773	23.0		
1000	1	0.0253	25.2448	21.0	20.8	0.76
	2	0.0254	25.4606	20.0		
	3	0.0244	24.4617	21.5		

Table C3 Pour point temperature of Phet crude when added EVA with 40% vinyl acetate content

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	Pour point (°C)	Average pour point (°C)	SD of pour point (°C)
100	1	0.0026	26.3126	30.0	29.5	0.50
	2	0.0026	26.5585	29.0		
	3	0.0028	27.8609	29.5		
200	1	0.0059	29.6584	28.0	28.7	0.58
	2	0.0056	28.0086	29.0		
	3	0.0050	25.2175	29.0		
400	1	0.0105	26.3535	24.0	24.7	1.15
	2	0.0102	25.5637	24.0		
	3	0.0101	25.4648	26.0		
600	1	0.0158	26.5589	22.5	22.3	0.76
	2	0.0154	26.0056	23.0		
	3	0.0147	24.4651	21.5		
800	1	0.0205	25.7195	21.5	20.5	1.32
	2	0.0195	24.6798	19.0		
	3	0.0202	25.4556	21.0		
1000	1	0.0261	26.1942	15.0	16.3	1.15
	2	0.0269	26.9894	17.0		
	3	0.0253	25.3331	17.0		

Table C4 Pour point temperature of Phet crude when added EVAFLEX with 28% vinyl acetate content

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	Pour point (°C)	Average pour point (°C)	SD of pour point (°C)
100	1	0.0027	26.7920	23.0	24.5	1.32
	2	0.0027	26.6095	25.0		
	3	0.0023	23.3022	25.5		
200	1	0.0048	24.0373	19.5	20.2	0.76
	2	0.0049	24.3979	20.0		
	3	0.0052	26.1640	21.0		
400	1	0.0098	24.8450	20.5	20.2	0.29
	2	0.0099	24.8710	20.0		
	3	0.0103	25.8538	20.0		
600	1	0.0153	25.5793	24.0	23.7	1.04
	2	0.0148	24.7218	24.5		
	3	0.0156	26.0634	22.5		
800	1	0.0202	25.3407	21.5	20.5	1.32
	2	0.0199	24.9180	19.0		
	3	0.0201	25.1430	21.0		
1000	1	0.0236	23.7684	20.0	19.8	0.76
	2	0.0255	25.5686	19.0		
	3	0.0255	25.7543	20.5		

Table C5 Pour point temperature of Phet crude when added EVAFLEX with 33% vinyl acetate content

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	Pour point (°C)	Average pour point (°C)	SD of pour point (°C)
100	1	0.0023	23.3796	26.5	27.3	0.76
	2	0.0026	26.5756	27.5		
	3	0.0024	23.8562	28.0		
200	1	0.0047	23.8979	26.5	25.2	1.53
	2	0.0052	26.1750	23.5		
	3	0.0052	26.3001	25.5		
400	1	0.0100	25.6999	23.0	23.2	0.29
	2	0.0093	23.3850	23.5		
	3	0.0092	23.0719	23.0		
600	1	0.0155	25.8842	22.5	23.7	1.26
	2	0.0146	24.5245	25.0		
	3	0.0150	25.2910	23.5		
800	1	0.0197	24.7105	23.0	20.7	2.08
	2	0.0194	24.2603	19.0		
	3	0.0203	25.3836	20.0		
1000	1	0.0247	24.6889	18.0	18.2	0.76
	2	0.0257	25.7148	17.5		
	3	0.0251	25.2702	19.0		

Table C6 Pour point temperature of Phet crude when added EVAFLEX with 41% vinyl acetate content

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	Pour point (°C)	Average pour point (°C)	SD of pour point (°C)
100	1	0.0026	25.6317	30.0	30.0	0.00
	2	0.0026	26.0206	30.0		
	3	0.0026	26.4731	30.0		
200	1	0.0048	24.1979	29.5	30.0	0.50
	2	0.0048	24.0797	30.0		
	3	0.0050	24.9756	30.5		
400	1	0.0103	25.9599	29.5	29.7	0.76
	2	0.0097	24.1165	29.0		
	3	0.0096	24.0752	30.5		
600	1	0.0149	24.8383	30.0	30.2	0.29
	2	0.0141	23.6610	30.0		
	3	0.0148	24.6745	30.5		
800	1	0.0198	24.7935	28.0	28.8	1.04
	2	0.0209	26.1650	28.5		
	3	0.0206	25.7732	30.0		
1000	1	0.0251	25.1224	27.0	26.7	0.58
	2	0.0242	24.2943	26.0		
	3	0.0251	25.1623	27.0		

Appendix D Effect of Poly(ethylene-co-vinyl acetate) on ROB Reduction Using Glass Container

Table D1 % ROB reduction of crude when using EVA with 25% vinyl acetate content and preheated at 60°C

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	% ROB	% average ROB (°C)	%SD of ROB
1000	1	0.2203	220.62	12.95	12.5	0.63
	2	0.2397	240.09	12.05		
800	1	0.1861	232.69	11.68	9.9	1.72
	2	0.1928	241.52	9.68		
	3	0.1799	225.18	8.25		
600	1	0.1463	243.79	8.18	8.0	0.70
	2	0.1438	239.98	7.22		
	3	0.1405	235.21	8.58		
400	1	0.0957	239.85	7.92	7.8	0.41
	2	0.0950	237.76	8.18		
	3	0.0961	240.17	7.38		
200	1	0.0482	241.64	6.12	7.2	1.17
	2	0.0477	238.73	8.44		
	3	0.0487	244.71	7.02		
100	1	0.0245	246.23	8.59	8.4	0.83
	2	0.0241	241.37	7.49		
	3	0.0242	242.95	9.12		

Table D2 % ROB reduction of crude when using EVA with 40% vinyl acetate content and preheated at 60°C

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	% ROB	% average ROB (°C)	SD of % ROB
1000	1	0.2402	240.35	12.0	10.5	1.46
	2	0.2416	241.76	9.1		
	3	0.2403	240.72	10.2		
800	1	0.1931	241.60	25.9	25.8	5.44
	2	0.1914	239.81	31.1		
	3	0.1921	240.29	20.2		
600	1	0.1439	240.26	42.0	43.5	1.32
	2	0.1442	240.45	44.2		
	3	0.1454	242.80	44.3		
400	1	0.0986	246.73	100.0	100.0	0.00
	2	0.0963	240.92	100.0		
	3	0.0956	239.09	100.0		
200	1	0.0477	238.39	100.0	100.0	0.00

Table D3 % ROB reduction of crude when using EVAFLEX with 28% vinyl acetate content and preheated at 60°C

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	% ROB	% average ROB (°C)	%SD of ROB
1000	1	0.2416	242.10	6.9	6.5	0.41
	2	0.2412	241.14	6.4		
	3	0.2404	240.76	6.1		
800	1	0.1919	240.17	6.8	6.5	0.26
	2	0.1915	239.53	6.3		
	3	0.1914	240.14	6.5		
600	1	0.1463	245.29	7.6	7.5	0.10
	2	0.1437	239.73	7.4		
	3	0.1433	239.32	7.6		
400	1	0.0965	241.59	11.3	9.5	1.64
	2	0.0957	239.47	8.9		
	3	0.0752	188.27	8.2		
200	1	0.0493	246.59	16.0	15.9	0.38
	2	0.0484	242.27	16.2		
	3	0.0477	238.60	15.5		
100	1	0.0249	249.09	52.4	59.5	6.51
	2	0.0236	236.23	65.2		
	3	0.0242	241.91	60.8		

Table D4 % ROB reduction of crude when using EVAFLEX with 33% vinyl acetate content and preheated at 60°C

Concentration (ppm)	Run	Inhibitor wt. (g)	Crude wt. (g)	% ROB	% average ROB (°C)	SD of % ROB
1000	1	0.2399	239.77	4.0	3.5	0.46
	2	0.2411	241.03	3.4		
	3	0.2397	240.25	3.1		
800	1	0.1927	241.77	10.0	10.2	0.25
	2	0.1929	241.47	10.0		
	3	0.1925	241.26	10.5		
600	1	0.1439	240.50	14.2	10.7	3.09
	2	0.1436	239.36	9.4		
	3	0.1441	240.36	8.5		
400	1	0.0985	248.38	15.1	14.5	1.83
	2	0.0960	240.27	15.9		
	3	0.0953	238.50	12.4		
200	1	0.0459	229.64	20.8	25.7	4.18
	2	0.0485	242.49	27.9		
	3	0.0500	251.90	28.2		
100	1	0.0234	234.82	100.0	100.0	0.00
	2	0.0235	235.56	100.0		

Table D5 % ROB reduction with pour point temperature of crude when using EVA and preheated at 60°C

Concentration (ppm)	25% VA				40% VA			
	PP (°C)	SD PP	%ROB reduction	SD ROB	PP (°C)	SD PP	%ROB reduction	SD ROB
0	30.83	0.76	0.00	0.00	30.83	0.76	0.00	0.00
100	22.83	0.76	91.60	0.83	29.50	0.50	0.00	0.00
200	20.67	0.58	92.81	1.17	28.67	0.58	0.00	0.00
400	20.33	0.58	92.17	0.41	24.67	1.15	0.00	0.00
600	20.00	0.50	92.00	0.70	22.33	0.76	56.51	1.32
800	24.67	1.53	90.13	1.72	20.50	1.32	74.24	5.44
1000	24.67	0.58	87.50	0.63	16.33	1.15	89.55	1.46

Table D6 % ROB reduction with pour point temperature of crude when using EVAFLX and preheated at 60°C

Concentration (ppm)	28% VA				33% VA			
	PP (°C)	SD PP	%ROB reduction	SD ROB	PP (°C)	SD PP	%ROB reduction	SD ROB
0	30.83	0.76	0.00	0.00	30.83	0.76	0.00	0.00
100	24.50	1.32	40.50	6.51	27.33	0.76	0.00	0.00
200	20.17	0.76	84.11	0.38	25.17	1.53	74.34	4.18
400	20.17	0.29	90.51	1.64	23.17	0.29	85.49	1.83
600	23.67	1.04	92.46	0.10	23.67	1.26	89.29	3.09
800	20.50	1.32	93.50	0.26	20.67	2.08	89.83	0.25
1000	19.83	0.76	93.54	0.41	18.17	0.76	96.51	0.46

Appendix E Pour Point Temperature of Oil and ROB Fractions Obtained from Glass Container

Table E1 Pour point temperature of oil and ROB fractions when using EVA with 25 and 40% vinyl acetate content

Concentration (ppm)	25% VA				40% VA			
	Oil (°C)	S.D. (°C)	ROB (°C)	S.D. (°C)	Oil (°C)	S.D. (°C)	ROB (°C)	S.D. (°C)
0	30.8	0.8	30.8	0.8	30.8	0.8	30.8	0.8
100	24.3	0.4	30.3	0.4	30.8	0.8	31.0	0.7
200	24.0	0.0	29.0	0.7	30.8	0.8	30.8	0.4
400	24.5	0.0	28.0	-	30.4	0.6	29.8	1.1
600	25.3	0.4	29.5	-	28.3	0.4	29.8	0.4
800	25.0	0.0	29.0	0.0	23.3	0.4	28.5	-
1000	26.3	0.4	30.5	-	23.0	0.0	28.5	2.1

Table E2 Pour point temperature of oil and ROB fractions when using EVAFLEX with 28 and 33% vinyl acetate content

Concentration (ppm)	28% VA				33% VA			
	Oil (°C)	S.D. (°C)	ROB (°C)	S.D. (°C)	Oil (°C)	S.D. (°C)	ROB (°C)	S.D. (°C)
0	30.8	0.8	30.8	0.8	30.8	0.8	30.8	0.8
100	26.8	1.1	27.5	-	29.0	0.7	30.3	0.4
200	24.8	0.4	28.0	-	27.8	0.4	30.8	0.4
400	22.5	0.7	26.3	0.4	23.8	0.4	28.3	0.4
600	21.3	0.4	29.3	0.4	21.5	0.7	27.3	0.4
800	19.3	0.4	28.5	0.0	20.3	0.4	24.3	0.4
1000	18.0	0.0	28.0	0.0	18.8	0.4	23.3	0.4

Appendix F Effect of EVAFLEX on Pour Point Reduction by Using Rail Train Wagon

Table F1 Pour point reduction of both oil and ROB fractions with and without inhibitor at Bung Phra Depot

Run	Bung Phra Depot							
	EVAFLEX with 33% VA content				Without Inhibitor			
	Crude		ROB*		Crude		ROB*	
	48°C**	60°C***	48°C**	60°C***	48°C**	60°C***	48°C**	60°C***
Run 1	28.0	23.5	31.5	31.5	30.0	30.0	31.5	30.5
Run 2	28.5	23.5	38.5	37.5	30.0	30.0	36.0	35.0
Run 3	29.0	23.2	37.0	38.0	30.5	30.5	34.5	35.0
Run 4	28.5	23.5	34.5	36.0	30.5	31.0	33.0	33.0
Run 5	28.2	22.0	36.0	37.0	30.5	30.0	36.0	36.5

* After the train got back to Bung Phra depot, ** Preheated at 48°C, *** Preheated at 60°C

Table F2 Pour point reduction of both oil and ROB fractions with and without inhibitor at Bangchak refinery

Run	Bangchak Refinery							
	EVAFLEX with 33% VA content				Without Inhibitor			
	Crude		ROB		Crude		ROB	
	48°C	60°C	48°C	60°C	48°C	60°C	48°C	60°C
Run 1	27.5	23.5	31.0	32.5	30.0	30.5	30.0	31.0
Run 2	28.0	23.5	32.5	31.5	30.5	31.0	30.5	31.0
Run 3	29.5	23.0	35.0	34.5	31.0	30.5	31.5	31.5
Run 4	28.5	23.5	35.5	36.0	30.5	30.0	33.0	33.5
Run 5	28.5	23.5	36.0	36.0	30.5	31.0	33.0	32.5

Table F3 Pour point reduction of ROB when using EVAFLEX with 33% vinyl acetate content

Concentration (ppm)	Inhibitor wt.. (g)	Crude wt. (g)	Pour point (°C)
0	-	25.0360	33.5
100	0.0030	30.5297	36.0
200	0.0042	21.2299	34.5
400	0.0104	26.1267	33.0
600	0.0143	24.1723	33.5
800	0.0194	25.1060	33.5
1000	0.0245	24.5065	34.0

Appendix G Volume of ROB in Rail Train Wagon

Runs	Depot	Refinery
1	1 →	→ 1
2	2 ←	→ 2
3	3 ←	→ 3
4	4 ←	→ 4
5	5 ←	→ 5

The volume of the ROB at Bung Phra depot was higher than that at Bangchak refinery, as shown in Figure G1 and G2, respectively because the ROB volume adhering on the sidewall of the wagon move to the bottom of the wagon during 12 hours transportation back to Bung Phra.

The amount of ROB after adding the inhibitor was higher than that without inhibitor for every experimental run. This could be due to the formation of aggregates between inhibitor molecules and high molecular weight paraffinic hydrocarbons.

The differences between lab results and rail train wagon results can be due to poor mixing of inhibitor with crude in the wagon, this inhomogineity of the mixture being enhanced by an inefficient preheating temperature (48°C).

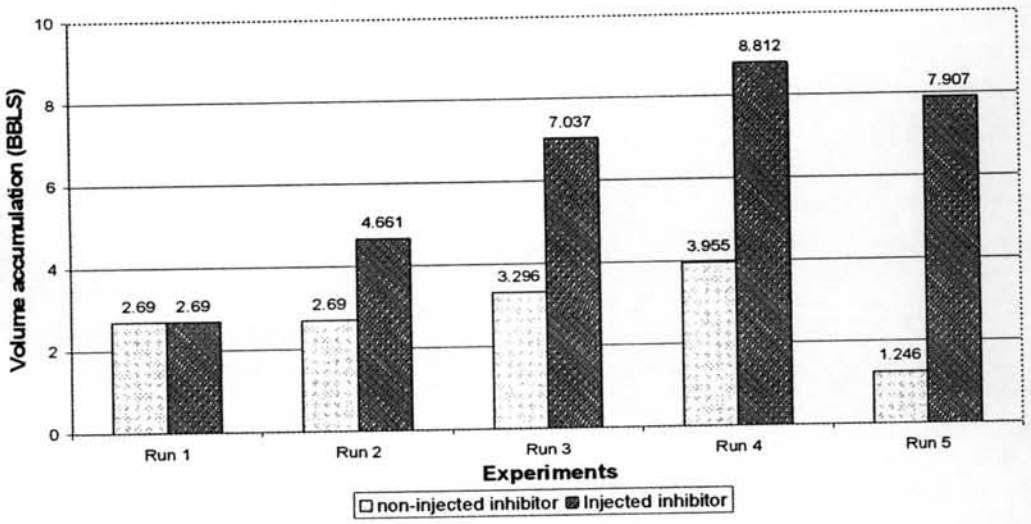

Figure G1 The amount of ROB at Bung Phra depot.

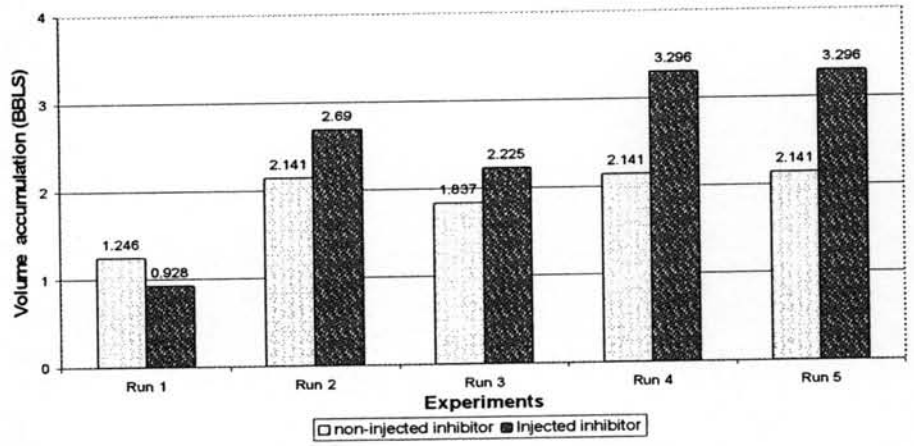

Figure G2 The amount of ROB at Bangchak refinery

Appendix H Chromatograms of oil and ROB with EVAFLEX with 28%VA

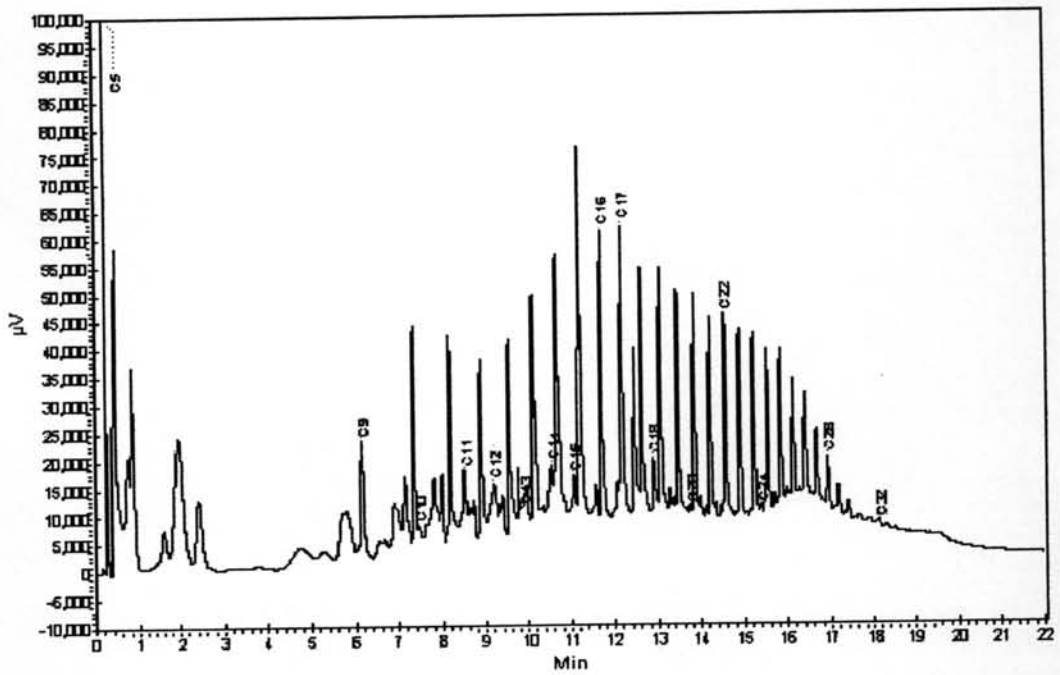

Figure H1 Chromatogram of oil fraction with EVAFLEX with 28% vinyl acetate content at 72 ppm.

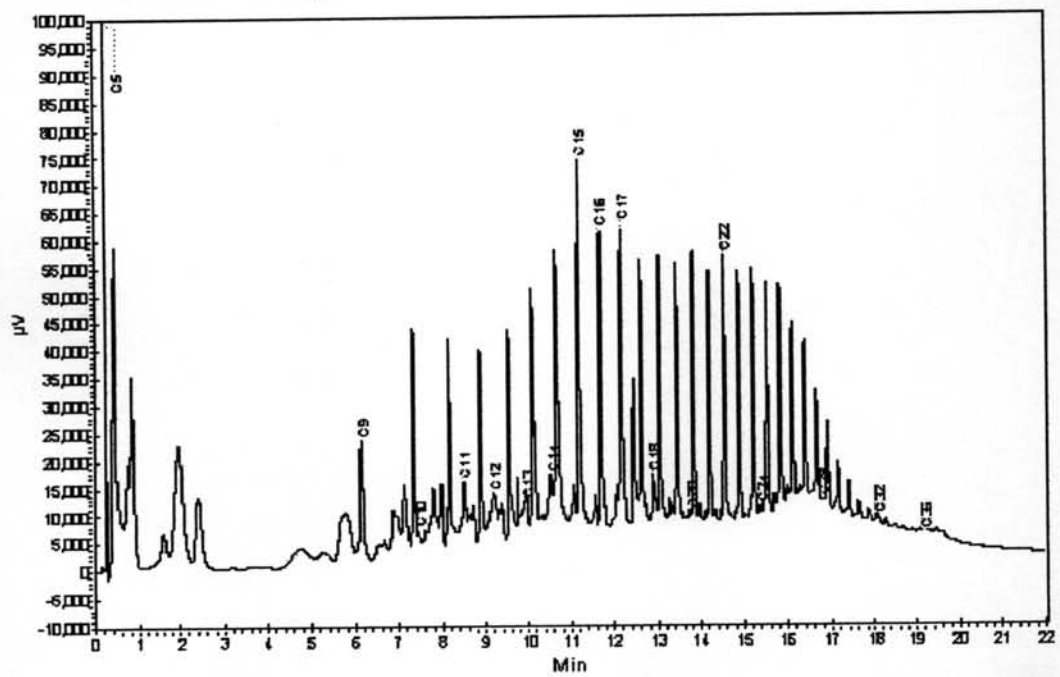

Figure H2 Chromatogram of ROB fraction with EVAFLEX with 28% vinyl acetate content at 28 ppm.

Appendix I Calculation of Amount of Inhibitor in Oil and ROB Fractions from n-Paraffins Enthalpy

EVAFLEX with 28% vinyl acetate content at 100 ppm was added into the original crude oil equilibrated for 12 h at 30°C. The crude fluid was drained off which was called oil fraction and the remaining in the container call ROB fraction.

Assumption

After separation into two fractions, oil fraction contain EVAFLEX = A ppm

ROB fraction contain EVAFLEX = B ppm

Therefore, $A + B = 100$ ppm

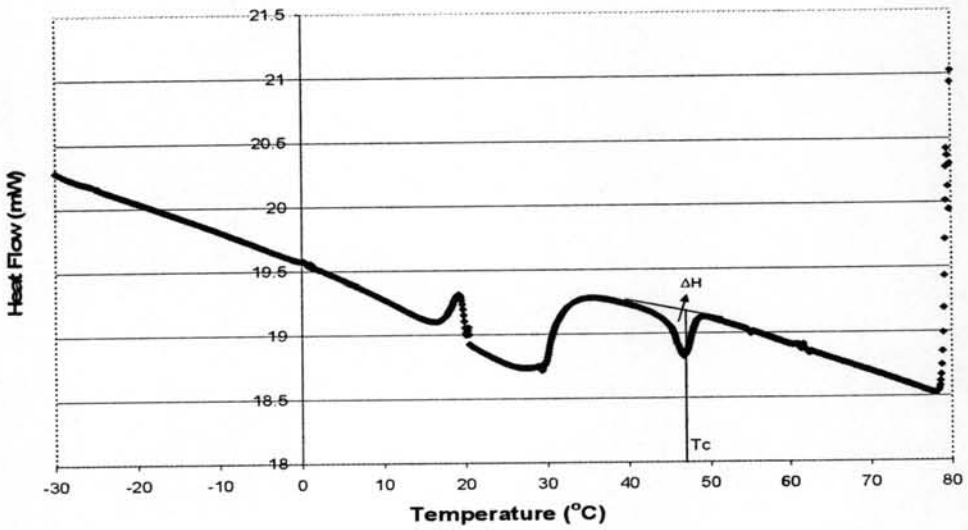

Figure I1 DSC thermogram obtained by cooling from 80 to -30°C of oil fraction with EVAFLEX with 28% vinyl acetate content at 100+A ppm

Table I1 Enthalpy change of oil and ROB fractions

Conc. (ppm)	Oil ΔH (J/g)	Conc. (ppm)	ROB ΔH (J/g)
100+A	1.127	100+B	0.996
200+A	1.031	200+B	0.926
400+A	0.967	400+B	0.941
600+A	0.878	600+B	0.886
800+A	0.804	800+B	0.891
1000+A	0.684	1000+B	0.858

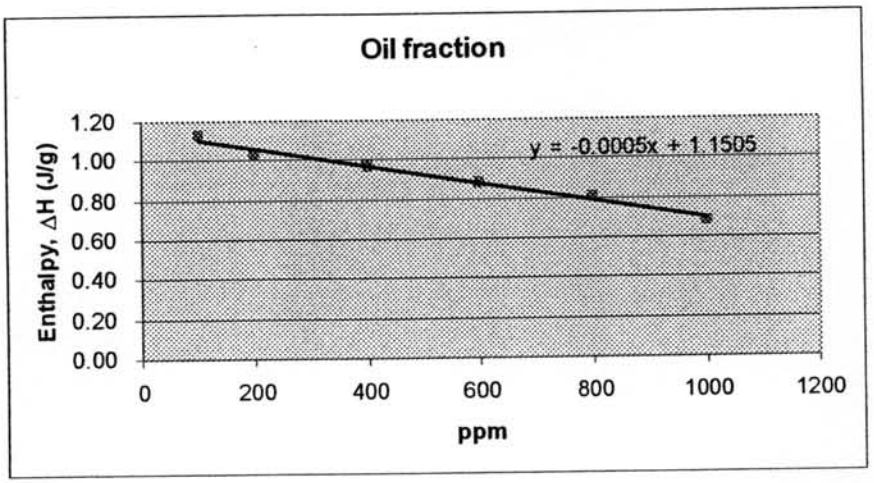

Figure I2 Plot of data in Table I1 for oil fraction when A = 0 ppm.

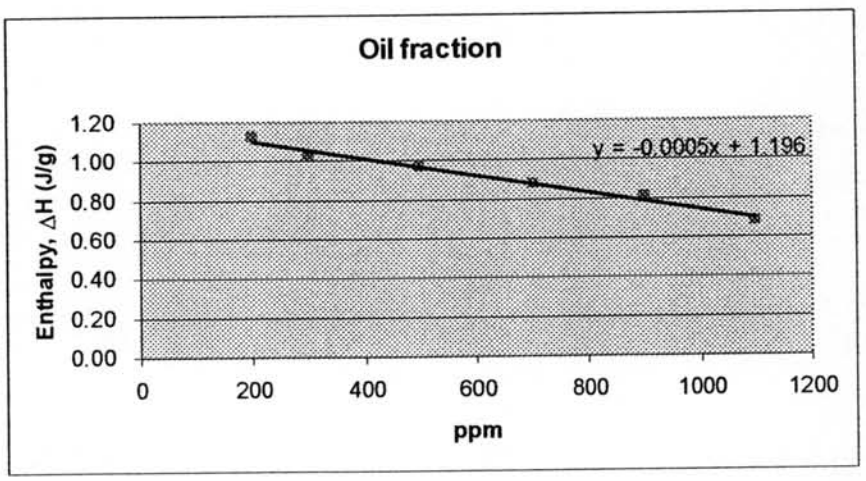

Figure I3 Plot of data in Table I1 for oil fraction when A = 100 ppm.

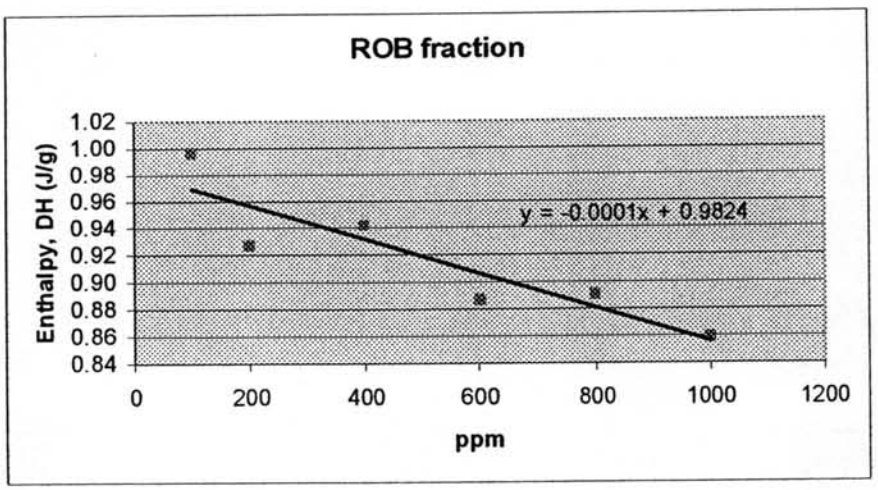

Figure I4 Plot of data in Table I1 for ROB fraction when B = 0 ppm.

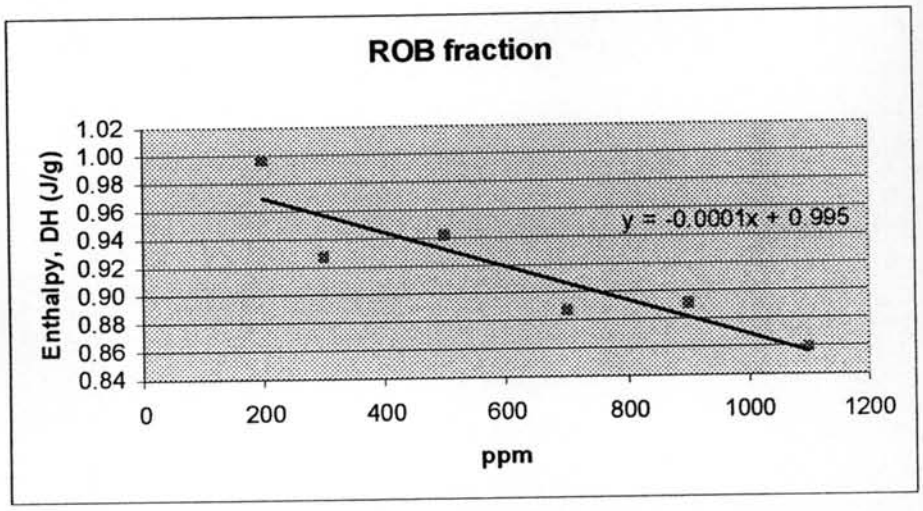

Figure I5 Plot of data in Table I1 for ROB fraction when B = 100 ppm.

From Figures I2 and I3, when concentration of EVAFLEX in oil fraction changes 100 ppm, the intercept changes = 1.1960 – 1.1505 = 0.0455 J/g

From Figures I4 and I5, when concentration of EVAFLEX in ROB fraction change 100 ppm, the intercept changes = 0.995 – 0.9824 = 0.0126 J/g

Therefore, % EVAFLEX in oil fraction = (0.0455*100) / (0.0455 + 0.0126) = 78.31 %

% EVAFLEX in ROB fraction = (0.0126*100) / (0.0455 + 0.0126) = 21.69 %

Thus, the inhibitor was calculated in oil = 78.31 ppm and in ROB = 21.69 ppm.

The validity of the EVAFLEX in oil fraction was checked by finding a new intercept by substituting A of 78.31 ppm in Table I1 and compare with the intercept at 0-100 ppm EVAFLEX.

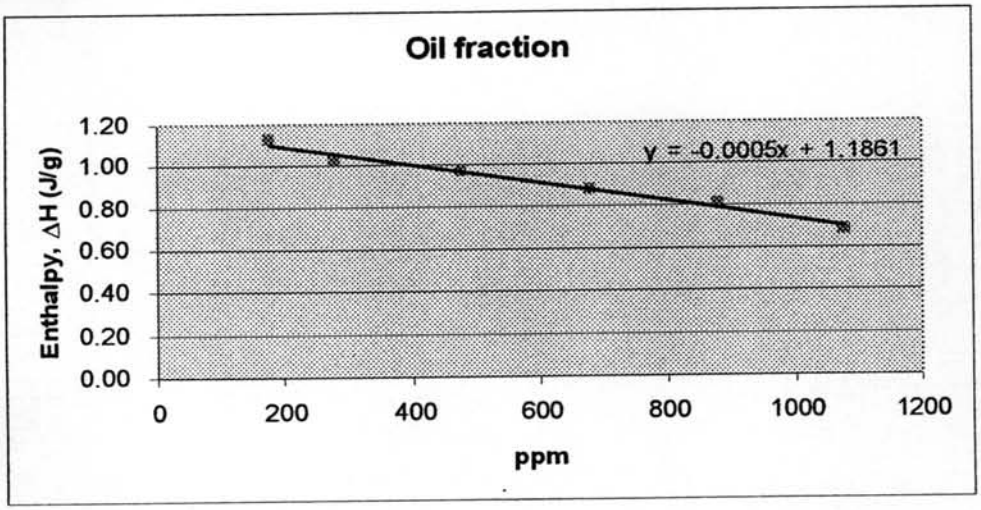

Figure I6 Plot of data in Table I1 for oil fraction when A = 78.31 ppm.

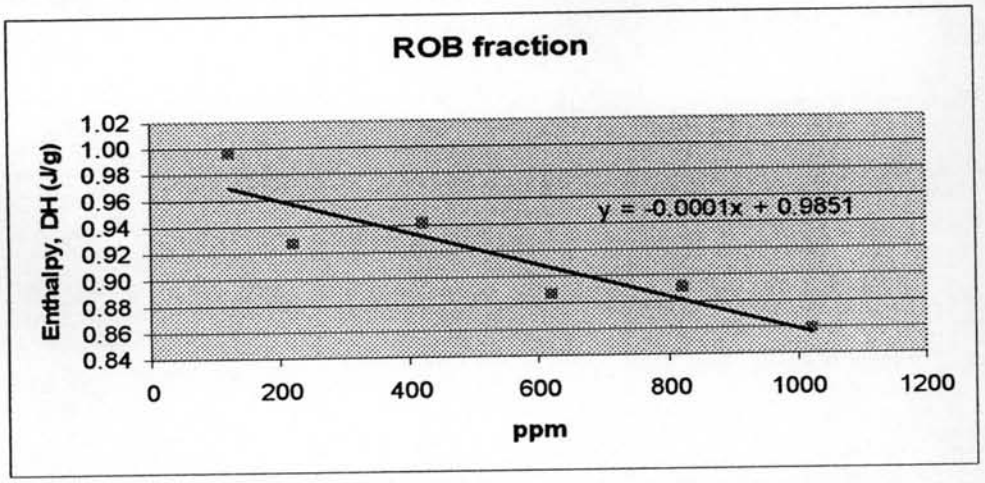

Figure I7 Plot of data in Table I1 for ROB fraction when B = 21.69 ppm

From Figure I6, the new intercept (enthalpy) = 1.1861 J/g compared to that of experiment (1.154 J/g) yielded the error less than 3%.

From Figure I7 the new intercept (enthalpy) = 0.9851 J/g compared to that of experiment (= 0.983 J/g yielded the error less than 1%.

It can be concluded that the amount of inhibitor in the oil and ROB fractions are 78 and 22 ppm, respectively.

Appendix J Calculation of Total Disposal Cost per Year with and without Inhibitor Addition

The company is currently losing money for cleaning wax in the wagon tanks and loss of opportunity to sale ROB as crude. The cost calculation is based on the information in 2006 provided by the company as follows:

1.) Steam for cleaning ROB in RTW = 20,000 Baht/tank
2.) Water treatment for oil contaminated wastewater = 2500 Baht/ton water
3.) Transport of contaminated water = 6,000 Baht/trip and 6 ton/trip
4.) Maximum ROB measured = 6% of crude production
5.) Minimum ROB measured = 2.25% of crude production
6.) Maximum sludge wax measured after cleaning wagon tanks = 4,000 ton/year
7.) Minimum sludge wax measured after cleaning wagon tanks = 1,500 ton/year
8.) Production rate = 18,800 bbl/day
9.) Wagon cleaning = 380 tanks/year
10.) Contaminated water produced = 80 ton water/year
11.) Rail transport cost = 55.5 Baht/bbl.
12.) Sale of ROB as crude = 26.58 US$/bbl. = 7,627.12 Baht/ton

Important data used in the calculation are,

1.) Crude oil production = 18,800 bbl/day = 2,391,360 kg/day
2.) Specific gravity of crude = 0.8
3.) Conversion 1 bbl. = 159 liter
4.) Exchange rate of 1 US$ = 36.50 Baht

Without Inhibitor

Total disposal cost = Steam + Water treatment + Transport + Rail freight

$$\textit{Steam cost} = \frac{20{,}000 baht}{\tan k} x \frac{380 \tan ks}{year} = 7{,}600{,}000 \text{ baht/year}$$

$$\textit{Water treatment cost} = \frac{2{,}500 baht}{tonWater} x \frac{80 tonWater}{year} = 200{,}000 \text{ Baht/year}$$

$$\textit{Transport cost of contaminated water} = \frac{6{,}000 baht}{trip} x \frac{80 tonWater}{year} x \frac{6 tonWater}{trip}$$

$$= \quad 80{,}000 \text{ bahts/year}$$

$$\textit{Rail freight cost} \quad = \frac{55.5 baht}{bbl} x \frac{bbl}{159 liter} x \frac{liter}{0.8 kg} x \frac{1{,}000 kg}{ton}$$

$$= (436.32 \text{ baht/ton}) \quad = \frac{436.32 baht}{ton} x \frac{19{,}639 ton}{year}$$

$$= 8{,}568{,}923 \text{ baht/year}$$

Therefore, the total disposal cost = 7,600,000 + 200,000 + 80,000 + 8,568,923

= 16,448,923 Baht/year

With Inhibitor

Cost of Inhibitor

Information for economic assessment is as follows:

	EVAFLEX (28% VA)[1]	EVAFLEX (33% VA)[1]	Toluene [3]	Diesel[4]	H. Naphtha[5]	H. Aromatic[5]
US$/ton			990		713	572.46
baht/ton			36,135			
baht/kg	90	95	36.135	23.56	26.02	20.89

([1]Onyx Limted source: updated 2007), [4] Bangchak source: updated Aug 2007, [5] ATC source: updated Aug 2007)

Example of inhibitor solution preparation

EVA (28%VA) at 200 ppm (wt/wt) in 1:5 weight ratio of EVA to solvent,

$$\text{200 ppm EVA} \quad = \frac{200 kgEVA}{1{,}000{,}000 kgCrude} x \frac{1{,}000 kgCrude}{ton}$$

$$= \text{ 0.2 kg EVA/ton crude}$$

$$\text{EVA in solvent} \quad = 1{:}5 \quad = \frac{0.2 kgEVA / tonCrude}{1.0 kgSolvent}$$

Thus, 200 ppm EVA solution in 1 ton of crude contains 0.2 kg EVA and 1.0 kg solvent.

Table J1 The amount of inhibitor solution at various concentrations.

EVA:Solvent = 1:5			Cost of solvent per ton Crude (baht)			
ppm EVA solution	kg EVA / ton Crude	kg Sovent / ton Crude	Toluene	Diesel	Naphtha	H.Aromatic
100	0.1	0.5	18.0675	11.78	13.01	10.445
200	0.2	1	36.135	23.56	26.02	20.89
400	0.4	2	72.27	47.12	52.04	41.78
600	0.6	3	108.405	70.68	78.06	62.67
800	0.8	4	144.54	94.24	104.08	83.56

Cost calculation of inhibitor and solvent

200 ppm EVA solution in 1 ton of crude contains 0.2 kg EVA and 1.0 kg solvent.

$$Inhibitor\ cost = \frac{90 baht}{kgEVA} x \frac{0.2 kgEVA}{1 tonCrude} = 18.0 \text{ baht EVA/ton Crude}$$

$$Toluene\ cost = \frac{36.135 baht}{kgToluene} x \frac{1 kgToluene}{1 tonCrude} = 36.135 \text{ baht } Toluene \text{ /ton crude}$$

$$Diesel\ cost = \frac{25 baht}{kgDiesel} x \frac{1 kgDiesel}{1 tonCrude} = 23.56 \text{ baht } Diesel \text{ /ton crude}$$

$$Naphtha\ cost = \frac{26.02 baht}{kgNaphtha} x \frac{1 kgNaphtha}{1 tonCrude} = 26.02 \text{ baht } Naphtha \text{ /ton crude}$$

$$Heavy\ Aromaitc\ cost = \frac{20.89 baht}{kgH.Aro.} x \frac{1 kgH.Aro.}{1 tonCrude} = 20.89 \text{ baht } Heavy\ Aromaitc \text{ /ton crude}$$

Table J2 Cost of materials at the condition 200 ppm EVA solution in 1 ton of crude contains 0.2 kg EVA and 1.0 kg solvent.

	Usage	baht / kg Material	baht Material / ton Crude	baht Material / **day Crude***	baht Material / **year Crude**
Inhibitor cost	*0.2kg*	90	18	43,044.48	15,711,235.20
Toluene cost	*1.0kg*	36.135	36.135	86,411.79	31,540,304.66
Diesel cost	*1.0kg*	23.56	23.56	56,340.44	20,564,261.18
Naphtha cost	*1.0kg*	26.02	26.02	62,223.19	22,711,463.33
Heavy Aro. cost	*1.0kg*	20.89	20.89	49,955.51	18,233,761.30

* Crude production 2,391.360 tons/day.

Disposal cost by varying the ROB reduction

Assumption: The maximum sludge wax can be converted is 4,000 ton/year (100% ROB reduction), and the minimum is 1,500 ton/year.

Therefore, working ROB reduction = 4000 – 1500 = 2500 ton/year

The working ROB reduction could be credited as crude after the inhibitor solution is applied. Thus,

The ROB credited as crude = [(4000 – 1500)*90] / 100 = 2,500 ton/year

$$\textit{Gain of income from saling ROB as crude} = \frac{2{,}500 tonROB}{year} x \frac{7{,}627.12 baht}{ton}$$

= 19,067,800 Baht/year

Appendix K Inhibitor Cost with Various Types of Solvents

Table K1 Cost of EVAFLEX with 28% vinyl acetate content in toluene solvent

Conc. (ppm)	EVA (kg/day)	EVA (Baht/day)	Toluene (kg/day)	Toluene (Baht/day)	Total inhibitor cost (Baht/day)	**Total inhibitor cost (Baht/year)**
100	239.14	21,522	1,195.68	43,212	64,734	23,627,952
200	478.27	43,044	2,391.36	86,424	129,468	47,255,904
400	956.54	86,089	4,782.72	172,848	258,936	94,511,808
600	1434.82	129,133	7,174.08	259,271	388,405	141,767,712
800	1913.09	172,178	9,565.44	345,695	517,873	189,023,616
1000	2391.36	215,222	11,956.8	432,119	647,341	236,279,520

Table K2 Cost of EVAFLEX with 33% vinyl acetate content in toluene solvent

Conc. (ppm)	EVA (kg/day)	EVA (Baht/day)	Toluene (kg/day)	Toluene (Baht/day)	Total inhibitor cost (Baht/day)	**Total inhibitor cost (Baht/year)**
100	239.14	22,718	1195.68	43,212	65,930	24,064,375
200	478.27	45,436	2391.36	86,424	131,860	48,128,750
400	956.54	90,872	4782.72	172,848	263,719	96,257,501
600	1434.82	136,308	7174.08	259,271	395,579	144,386,251
800	1913.09	181,743	9565.44	345,695	527,438	192,515,002
1000	2391.36	227,179	11956.8	432,119	659,298	240,643,752

Table K3 Cost of EVAFLEX with 28% vinyl acetate content in diesel solvent

Conc. (ppm)	EVA (kg)/day	EVA (Baht/day)	Diesel (kg/day)	Diesel (Baht/day)	Total inhibitor cost (Baht/day)	**Total inhibitor cost (Baht/year)**
100	239	21,522	1,196	28,170	49,692	18,137,748
200	478	43,044	2,391	56,340	99,385	36,275,496
400	957	86,089	4,783	112,681	198,770	72,550,993
600	1,435	129,133	7,174	169,021	298,155	108,826,489
800	1,913	172,178	9,565	225,362	397,540	145,101,986
1,000	2,391	215,222	11,957	281,702	496,925	181,377,482

Table K4 Cost of EVAFLEX with 33% vinyl acetate content in diesel solvent

Conc. (ppm)	EVA (kg)/day	EVA (Baht/day)	Diesel (kg/day)	Diesel (Baht/day)	Total inhibitor cost (Baht/day	**Total inhibitor cost (Baht/year)**
100	239	22,718	1,196	28,170	50,888	18,574,171
200	478	45,436	2,391	56,340	101,776	37,148,343
400	957	90,872	4,783	112,681	203,553	74,296,686
600	1,435	136,308	7,174	169,021	305,329	111,445,028
800	1,913	181,743	9,565	225,362	407,105	148,593,371
1,000	2,391	227,179	11,957	281,702	508,881	185,741,714

Table K5 Cost of EVAFLEX with 28% vinyl acetate content in naphtha solvent

Conc. (ppm)	EVA (kg)/day	EVA (Baht/day)	Naphtha (kg/day)	Naphtha (Baht/day)	Total inhibitor cost (Baht/day	**Total inhibitor cost (Baht/year)**
100	239	21,522	1,196	31,112	52,634	19,211,349
200	478	43,044	2,391	62,223	105,268	38,422,699
400	957	86,089	4,783	124,446	210,535	76,845,397
600	1,435	129,133	7,174	186,670	315,803	115,268,096
800	1,913	172,178	9,565	248,893	421,071	153,690,794
1,000	2,391	215,222	11,957	311,116	526,338	192,113,493

Table K6 Cost of EVAFLEX with 33% vinyl acetate content in naphtha solvent

Conc. (ppm)	EVA (kg)/day	EVA (Baht/day)	Naphtha (kg/day)	Naphtha (Baht/day)	Total inhibitor cost (Baht/day	**Total inhibitor cost (Baht/year)**
100	239	22,718	1,196	31,112	53,830	19,647,772
200	478	45,436	2,391	62,223	107,659	39,295,545
400	957	90,872	4,783	124,446	215,318	78,591,090
600	1,435	136,308	7,174	186,670	322,977	117,886,635
800	1,913	181,743	9,565	248,893	430,636	157,182,180
1,000	2,391	227,179	11,957	311,116	538,295	196,477,725

Table K7 Cost of EVAFLEX with 28% vinyl acetate content in heavy aromatic solvent

Conc. (ppm)	EVA (kg)/day	EVA (Baht/day)	H. Arom (kg/day)	H. Arom (Baht/day)	Total inhibitor cost (Baht/day	**Total inhibitor cost (Baht/year)**
100	239	21,522	1,196	24,978	46,500	16,972,498
200	478	43,044	2,391	49,956	93,000	33,944,996
400	957	86,089	4,783	99,911	186,000	67,889,993
600	1,435	129,133	7,174	149,867	279,000	101,834,989
800	1,913	172,178	9,565	199,822	372,000	135,779,986
1,000	2,391	215,222	11,957	249,778	465,000	169,724,982

Table K8 Cost of EVAFLEX with 33% vinyl acetate content in heavy aromatic solvent

Conc. (ppm)	EVA (kg)/day	EVA (Baht/day)	H.Arom (kg/day)	H. Arom (Baht/day)	Total inhibitor cost (Baht/day	**Total inhibitor cost (Baht/year)**
100	239	22,718	1,196	24,978	47,696	17,408,921
200	478	45,436	2,391	49,956	95,391	34,817,843
400	957	90,872	4,783	99,911	190,783	69,635,686
600	1,435	136,308	7,174	149,867	286,174	104,453,529
800	1,913	181,743	9,565	199,822	381,565	139,271,372
1,000	2,391	227,179	11,957	249,778	476,957	174,089,214

CURRICULUM VITAE

Name: Mr. Perapon Sirijitt

Date of Birth: September 7, 1983

Nationality: Thai

University Education:

2001-2005 Bachelor Degree of Chemical Engineering, Faculty of Engineering, Thammasat University, Bangkok, Thailand

Working Experience:

2004	Position:	Summer Internship Student
	Company name:	Thai Plastics and Chemicals Co., Ltd

Presentation:

1. P. Sirijitt, C. Saiwan, T. Sreethawong, and E. Behar (2006, December 3-5) Study of Inhibition and Dissolution of Wax Deposition for Phet Crude Oil. Oral presented at the 13th RSCE 2006, Nanyang Technological University, Singapore.