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## **APPENDIX**

### Kinetic Analysis of Asphaltene Dissolution

**Wt. Sample** 0.0249 g 24.9 mg  
**Wt. Paper ( before)** 0.0743 g 74.3 mg  
**Wt Paper ( after)** 0.0765 g 76.5 mg  
**Wt. Undiss. Asph** 0.0022 g 2.2 mg %Undissolved 8.835341

**Equation** C = 46.95 \*Abs **Vol. of Solvent Mixture** 100 ml  
**Flow rate** 1 ml/min **Total time** 100 min  
**Solvent** 70% toluene **Time Interval for Sample Collection** 2 min 120 sec  
**Vol. Solvent in Each Vial** 2 ml 0.002 l

No.	Time (min)	Solvent (ml)	Dilution factor	Abs.	Dilute Concentration	Concentration Conc.(mg/l)	wt. Diss. In each vial(mg)	Acc.wt. ( mg )	%dissolved	wt undiss.	ln(M/Mo)
0	0	0	0	0	0	0	0	0	0	24.9	0
1	2	2	101	0.5987	28.108965	2839.005465	5.67801093	5.6780109	22.80325675	19.221989	-0.258813
2	4	4	101	0.564	26.4798	2674.4598	5.3489196	11.026931	44.28486157	13.873069	-0.584918
3	6	6	101	0.5063	23.770785	2400.849285	4.80169857	15.828629	63.56879157	9.0713709	-1.009744
4	8	8	101	0.3609	16.944255	1711.369755	3.42273951	19.251369	77.31473337	5.6486314	-1.483455
5	10	10	101	0.1616	7.58712	766.29912	1.53259824	20.783967	83.46974639	4.1160332	-1.799978
6	12	12	101	0.0674	3.16443	319.60743	0.63921486	21.423182	86.03687434	3.4768183	-1.96875
7	14	14	21	0.1668	7.83126	164.45646	0.32891292	21.752095	87.35780976	3.1479054	-2.068131
8	16	16	21	0.1077	5.056515	106.186815	0.21237363	21.964468	88.2107159	2.9355317	-2.137979
9	18	18	21	0.0749	3.516555	73.847655	0.14769531	22.112164	88.80386976	2.7878364	-2.189602
10	20	20	11	0.1426	6.69507	73.64577	0.14729154	22.259455	89.39540205	2.6405449	-2.243883
11	22	22	11	0.0942	4.42269	48.64959	0.09729918	22.356754	89.78616181	2.5432457	-2.281427
12	24	24	11	0.0749	3.516555	38.682105	0.07736421	22.434119	90.09686145	2.4658815	-2.312318
13	26	26	2	0.3337	15.667215	31.33443	0.06266886	22.496787	90.34854361	2.4032126	-2.338061
14	28	28	2	0.299	14.03805	28.0761	0.0561522	22.55294	90.57405446	2.3470604	-2.361704
15	30	30	2	0.2456	11.53092	23.06184	0.04612368	22.599063	90.75929012	2.3009368	-2.381551
16	32	32	2	0.1945	9.131775	18.26355	0.0365271	22.63559	90.9059853	2.2644097	-2.397554
17	34	34	1	0.3758	17.64381	17.64381	0.03528762	22.670878	91.04770265	2.229122	-2.41326
18	36	36	1	0.3112	14.61084	14.61084	0.02922168	22.7001	91.1650588	2.1999004	-2.426456
19	38	38	1	0.2697	12.662415	12.662415	0.02532483	22.725424	91.26676494	2.1745755	-2.438034
20	40	40	1	0.2338	10.97691	10.97691	0.02195382	22.747378	91.35493289	2.1526217	-2.448181
21	42	42	1	0.21	9.8595	9.8595	0.019719	22.767097	91.43412566	2.1329027	-2.457384

No.	Time (min)	Solvent (ml)	Dilution factor	Abs.	Dilute Concentration	Concentration Conc.(mg/l)	wt. Diss. In each vial(mg)	Acc.wt. ( mg )	%dissolved	wt undiss.	ln(M/Mo)
22	44	44	1	0.1903	8.934585	8.934585	0.01786917	22.784966	91.5058894	2.1150335	-2.465797
23	46	46	1	0.1713	8.042535	8.042535	0.01608507	22.801052	91.57048807	2.0989485	-2.473431
24	48	48	1	0.149	6.99555	6.99555	0.0139911	22.815043	91.62667723	2.0849574	-2.480119
25	50	50	1	0.1371	6.436845	6.436845	0.01287369	22.827916	91.6783788	2.0720837	-2.486313
26	52	52	1	0.1276	5.99082	5.99082	0.01198164	22.839898	91.72649783	2.060102	-2.492112
27	54	54	1	0.123	5.77485	5.77485	0.0115497	22.851448	91.77288217	2.0485523	-2.497734
28	56	56	1	0.1129	5.300655	5.300655	0.01060131	22.862049	91.81545771	2.037951	-2.502923
29	58	58	1	0.1106	5.19267	5.19267	0.01038534	22.872434	91.8571659	2.0275657	-2.508032
30	60	60	1	0.0955	4.483725	4.483725	0.00896745	22.881402	91.89317976	2.0185982	-2.512464
31	62	62	1	0.0904	4.24428	4.24428	0.00848856	22.88989	91.92727036	2.0101097	-2.516679
32	64	64	1	0.0815	3.826425	3.826425	0.00765285	22.897543	91.9580047	2.0024568	-2.520493
33	66	66	1	0.0773	3.629235	3.629235	0.00725847	22.904802	91.98715518	1.9951984	-2.524124
34	68	68	1	0.0714	3.35223	3.35223	0.00670446	22.911506	92.01408072	1.9884939	-2.52749
35	70	70	1	0.0695	3.263025	3.263025	0.00652605	22.918032	92.04028976	1.9819679	-2.530778
36	72	72	1	0.0631	2.962545	2.962545	0.00592509	22.923957	92.0640853	1.9760428	-2.533772
37	74	74	1	0.0591	2.774745	2.774745	0.00554949	22.929507	92.08637241	1.9704933	-2.536584
38	76	76	1	0.0578	2.71371	2.71371	0.00542742	22.934934	92.10816928	1.9650659	-2.539342
39	78	78	1	0.0549	2.577555	2.577555	0.00515511	22.940089	92.12887253	1.9599107	-2.541969
40	80	80	1	0.0542	2.54469	2.54469	0.00508938	22.945179	92.14931181	1.9548214	-2.544569
41	82	82	1	0.0496	2.32872	2.32872	0.00465744	22.949836	92.16801639	1.9501639	-2.546954
42	84	84	1	0.0486	2.28177	2.28177	0.00456354	22.9544	92.18634386	1.9456004	-2.549297
43	86	86	1	0.0463	2.173785	2.173785	0.00434757	22.958747	92.20380398	1.9412528	-2.551534
44	88	88	1	0.0446	2.09397	2.09397	0.00418794	22.962935	92.22062301	1.9370649	-2.553694
45	90	90	1	0.0439	2.061105	2.061105	0.00412221	22.967057	92.23717807	1.9329427	-2.555824
46	92	92	1	0.0414	1.94373	1.94373	0.00388746	22.970945	92.25279036	1.9290552	-2.557837
47	94	94	1	0.0398	1.86861	1.86861	0.00373722	22.974682	92.26779928	1.925318	-2.559777
48	96	96	1	0.0407	1.910865	1.910865	0.00382173	22.978504	92.28314759	1.9214963	-2.561764
49	98	98	1	0.0372	1.74654	1.74654	0.00349308	22.981997	92.29717602	1.9180032	-2.563583

Prediction of NM5 Solubility from Fractionated NM1 Solubility Data

% toluene	Solubility of NM1 asphaltenes						predicted unfrac. NM5
	Experimental data			predicted data			
	Unfrac.	F70/30	F80/20	F90/10	F95/5	supernatant	
100	642.9368	296.366	357.3193	586.0893716	746.5954276	1262.406964	745.57797
90	558.1346	279.9167	317.3006	514.0088864	684.8252671	986.2635041	640.558976
80	489.9548	104.1419	286.6696	387.8734116	601.9033959	776.3280292	518.2592954
70	368.4993	46.25179	155.0142	302.2504704	580.6779151	711.7463479	426.6145594
60	157.7555	11.34227	27.38476	208.718826	407.8728201	499.2739374	269.6771053
50	59.04913	3.037219	3.085824	56.63429434	93.91797995	215.0002333	83.07468242
40	11.16484	0.953369	1.785344	38.94610955	43.18514273	57.89670447	34.17924352
30	3.434436	0.336012	0.596648	9.403744613	11.02535564	16.65315559	8.982854345
20	1.388838	0.143111	0.237565	2.438261393	2.824477165	4.164838735	2.322787194
10	0.510143	0.072195	0.107253	0.353613315	1.429802526	3.639441599	1.205958865

Calculation of Mass Transfer Coefficient ( $k_c$ )

%toluene	solubility (g/l)	dM/dt					
		5 ml/min	10 ml/min	15 ml/min	20 ml/min	25 ml/min	30 ml/min
10	0.69484	-0.1862			-0.4549		
20	1.743378	-0.629	-0.8715	-0.6765	-0.8282	-1.0221	-0.965
30	4.382905	-0.5117			-0.1713		
40	16.28101	-0.9019			-1.1655		
50	45.09191		-1	-2.25	-3.7519	-3.28	-2.98
60	153.0019	-4.38					
70	305.0097	-5.638	-12.416		-33.01		
80	365.3856	-8.178		-28.469		-44.8	-51.096
90	429.176						
100	516.2177	-9.4626	-21.176	-35.549	-50.998	-59.32	-68.451



**Sample : NM1 Asphaltene**

$$K = \exp \left( 1 - \frac{v_l}{v_m} + \ln \left( \frac{v_l}{v_m} \right) + v_l \left( \frac{\delta_l - \delta_m}{RT} \right)^2 \right)$$

asphaltene

$$v_l = \frac{1000 \cdot M_w}{0.017 \cdot M_w + 1080}$$

$$\delta_l = (A \cdot (0.017 \cdot M_w + 1080))^{0.5}$$

	molecular weight g/mol	density g/cm <sup>3</sup>	molar volume ( MW/density )	$\delta$ Mpa <sup>0.5</sup>	$\delta_l - \delta_m$
toluene	92.14	0.866	106.3972286	18.25	
heptane	100.21	0.684	146.505848	15.5	
pentane	72.2	0.626	115.3354633	14.3	
asphaltene-heptane	1022.841775	1.218	932.0691365	46.84844	31.348
asphaltene-pentane	674.3324452	1.218	617.8240056	46.72181	32.42181

solubility parameter of asphaltene

$$A = 0.438439181$$

A=the change in the heat of vaporization of asphaltene with a change in molar mass

$$\begin{aligned} \delta_i\text{-heptane} &= 46.848 \\ \delta_i\text{-pentane} &= 46.722 \end{aligned}$$

Basis 1 litre of solvent mixture

toluene fraction	heptane fraction	$v_m = x^t \cdot v^t + (1-x^t) \cdot v^h$	$\delta m$	mole toluene	mole heptane	K	solubility (g/l)	exp. Solubility (g/l)	error^2
0	1	146.506	15.5	0.000	6.825666101	173912.4	0.04016	0.00	0.001613
0.1	0.9	142.495	15.775	0.940	6.143	40617.25	0.178431	0.695	0.266844
0.2	0.8	138.484	16.05	1.880	5.461	9945.868	0.755175	1.743	0.975797
0.3	0.7	134.473	16.325	2.820	4.778	2551.195	3.048018	4.380	1.774176
0.4	0.6	130.462	16.6	3.759	4.095	684.8297	11.75139	16.280	20.50835
0.5	0.5	126.452	16.875	4.699	3.413	192.1648	43.412	45.090	2.815679
0.6	0.4	122.441	17.15	5.639	2.730	56.29457	154.8387	153.000	3.38072
0.7	0.3	118.430	17.425	6.579	2.048	17.19234	544.9883	305.000	
0.8	0.2	114.419	17.7	7.519	1.365	5.464675	2035.432	365.380	
0.9	0.1	110.408	17.975	8.459	0.683	1.804407	11623.94	429.176	
1	0	106.397	18.25	9.399	0.000	0.617591	-25140.3	516.210	
								Sum	29.72318

toluene fraction	pentane fraction	$v_m = x^t \cdot v^t + (1-x^t) \cdot v^h$	$\delta m$	mole toluene	mole pentane	K	solubility (g/l)	exp. Solubility (g/l)	error^2
0	1	115.335	14.3	0.000	8.670360111	112638.3	0.051904	0.00	0.002694
0.1	0.9	114.442	14.695	0.940	7.8033241	25450.68	0.231651	0.24719175	0.000242
0.2	0.8	113.548	15.09	1.880	6.936288089	6212.201	0.95707	0.74069259	0.046819
0.3	0.7	112.654	15.485	2.820	6.069252078	1638.016	3.661336	3.623561093	0.001427
0.4	0.6	111.760	15.88	3.759	5.202216066	466.5633	12.9795	14.68819013	2.919626
0.5	0.5	110.866	16.275	4.699	4.335180055	143.5543	42.73385	34.99416842	59.90262
0.6	0.4	109.973	16.67	5.639	3.468144044	47.71201	131.4653	135.4370359	15.7749
0.7	0.3	109.079	17.065	6.579	2.601108033	17.12923	383.7827		
0.8	0.2	108.185	17.46	7.519	1.734072022	6.64262	1105.734		
0.9	0.1	107.291	17.855	8.459	0.867036011	2.782431	3527.963		
1	0	106.397	18.25	9.399	0	1.258881	24480.22		
								Sum	78.64833

**1 dimensional Solubility Parameter Calculation(Molecular Weight Prediction)**

**Sample : NM5 Asphaltene**

$$K = \exp \left( 1 - \frac{v_l}{v_m} + \frac{\ln(v_l)}{v_m} + \frac{v_l(\delta_l - \delta_m)^2}{RT} \right)$$

*asphaltene*

$$v_l = \frac{1000 \cdot M_w}{0.017 \cdot M_w + 1080}$$

$$\delta_l = (A \cdot (0.017 \cdot M_w + 1080))^{0.5}$$

	molecular weight g/mol	density g/cm <sup>3</sup>	molar volume ( MW / density )	$\delta$ Mpa <sup>0.5</sup>	$\delta_l - \delta_m$
<b>toluene</b>	92.14	0.866	106.3972286	18.25	
<b>heptane</b>	100.21	0.684	146.505848	15.5	
<b>pentane</b>	72.2	0.626	115.3354633	14.3	
<b>asphaltene-heptane</b>	899.1894436	1.246	820.9629837	46.80355	31.304
<b>asphaltene-pentane</b>	585.0818362	1.246	536.7987278	46.68932	32.38932

solubility parameter of asphaltene

$$A = 0.440198449$$

A=the change in the heat of vaporization of asphaltene with a change in molar mass

$$\begin{aligned} \delta_i\text{-heptane} &= 46.804 \\ \delta_i\text{-pentane} &= 46.689 \end{aligned}$$

Basis 1 litre of solvent mixture

toluene fraction	heptane fraction	$vm=x^l \cdot v^l + (1-x)^l \cdot v^h$	$\delta m$	mole toluene	mole heptane	K	solubility (g/l)	exp. Solubility (g/l)	error^2
0	1	146.506	15.5	0.000	6.825666101	56291.93	0.109033	0.00	0.011888
0.1	0.9	142.495	15.775	0.940	6.143	15622.83	0.407695	0.510	0.010496
0.2	0.8	138.484	16.05	1.880	5.461	4520.81	1.460305	1.389	0.005108
0.3	0.7	134.473	16.325	2.820	4.778	1362.951	5.016092	9.06376323	16.38364
0.4	0.6	130.462	16.6	3.759	4.095	427.7352	16.55134	19.04983574	6.24248
0.5	0.5	126.452	16.875	4.699	3.413	139.5968	52.63042	59.049	41.19987
0.6	0.4	122.441	17.15	5.639	2.730	47.32601	162.4525	157.755	22.06206
0.7	0.3	118.430	17.425	6.579	2.048	16.64564	495.8023	368.499	
0.8	0.2	114.419	17.7	7.519	1.365	6.065288	1577.109	489.955	
0.9	0.1	110.408	17.975	8.459	0.683	2.285782	6392.904	558.135	
1	0	106.397	18.25	9.399	0.000	0.889248	-76308	642.937	
								Sum	85.91555

toluene fraction	heptane fraction	$vm=x^l \cdot v^l + (1-x)^l \cdot v^h$	$\delta m$	mole toluene	mole heptane	K	solubility (g/l)	exp. Solubility (g/l)	error^2
0	1	115.335	14.3	0.000	8.670360111	33247.93	0.152582	0.00	0.023281
0.1	0.9	114.442	14.695	0.940	7.8033241	9094.47	0.562545	0.36251973	0.04001
0.2	0.8	113.548	15.09	1.880	6.936288089	2660.3	1.939647	0.910928595	1.058261
0.3	0.7	112.654	15.485	2.820	6.069252078	832.1831	6.257008	5.377845495	0.772927
0.4	0.6	111.760	15.88	3.759	5.202216066	278.379	18.90315	12.99531398	34.90248
0.5	0.5	110.866	16.275	4.699	4.335180055	99.58122	53.62027	44.8842313	76.31837
0.6	0.4	109.973	16.67	5.639	3.468144044	38.09218	143.6574	151.3856412	59.72509
0.7	0.3	109.079	17.065	6.579	2.601108033	15.58136	368.3596	297.3209763	
0.8	0.2	108.185	17.46	7.519	1.734072022	6.815216	930.9715	359.0403007	
0.9	0.1	107.291	17.855	8.459	0.867036011	3.187512	2494.348	506.3489775	
1	0	106.397	18.25	9.399	0	1.594098	9256.102	538.6593602	
								Sum	172.8404

Sample : F90/10 NM1

vm-heptane 146.5  
 $\delta$ m-heptane 15.5  
 Mw 900.065671  
 vl 821.7518064  
 $\delta$ i 21.76920385  
 den\_Toluene 867 g/l  
 den\_Heptane 684 g/l

vm-toluene 106.228374  
 $\delta$ m-toluene 18.25  
 R 8.314  
 T 298  
 Mw\_Tol. 92.14 g/mol  
 Mw\_Hep. 100 g/mol

A 0.434548

Toluene (vol%)	Heptane (vol%)	vm	$\delta$ m	mol Toluene	mol Heptane	K	Solubility (g/l)	exp.Solubility (g/l)	error^2
0	100	146.5	15.5	0	6.84	25617.47	0.165758	0	0.027476
10	90	142.4728374	15.775	0.94095941	6.156	7345.148	0.599887	0.353613315	0.060651
20	80	138.4456747	16.05	1.88191882	5.472	2195.8	2.079994	2.438261393	0.128355
30	70	134.4185121	16.325	2.82287823	4.788	683.8701	6.918867	9.403744613	6.174615
40	60	130.3913495	16.6	3.76383764	4.104	221.6975	22.13076	38.94610955	282.7558
50	50	126.3641869	16.875	4.70479705	3.42	74.73473	68.40357	56.63429434	138.516
60	40	122.3370242	17.15	5.64575646	2.736	26.16794	206.7406	208.718826	3.913529
70	30	118.3098616	17.425	6.58671587	2.052	9.504848	630.5522	302.2504704	
80	20	114.282699	17.7	7.52767528	1.368	3.576125	2143.632	387.8734116	
90	10	110.2555363	17.975	8.46863469	0.684	1.391367	14517.79	514.0088864	
100	0	106.2283737	18.25	9.4095941	0	0.558713	-13237	586.0893716	
								Sum	431.5764

Sample : F80/20 NM1

vm-heptane 146.4213026  
 $\delta$ m-heptane 15.41408047  
Mw 1610.901791  
vl 1454.68948 T  
 $\delta$ i 21.93902725  
den\_Toluene 867 g/l  
den\_Heptane 684 g/l

vm-toluene 104.534651  
 $\delta$ m-toluene 18.5060026  
R 7.7373317  
T 298  
Mw\_Tol. 92.14 g/mol  
Mw\_Hep. 100 g/mol

A 0.444797

Toluene (vol%)	Heptane (vol%)	vm	$\delta$ m	mol Toluene	mol Heptane	K	Solubility (g/l)	exp.Solubility (g/l)	error^2
0	100	146.4213026	15.41408	0	6.84	6.06E+08	7.01E-06	0	4.92E-11
10	90	142.2326374	15.723273	0.94095941	6.156	38759209	0.000114	0.10725258	0.011479
20	80	138.0439723	16.032465	1.88191882	5.472	2751706	0.001659	0.237564653	0.055651
30	70	133.8553072	16.341657	2.82287823	4.788	216362.7	0.021837	0.596647643	0.330407
40	60	129.6666421	16.650849	3.76383764	4.104	18807.21	0.259712	1.785344175	2.327553
50	50	125.4779769	16.960042	4.70479705	3.42	1803.553	2.798098	3.085823963	0.082786
60	40	121.2893118	17.269234	5.64575646	2.736	190.3585	27.47822	27.38476125	0.008734
70	30	117.1006467	17.578426	6.58671587	2.052	22.05379	254.7165	172.4000502	
80	20	112.9119815	17.887618	7.52767528	1.368	2.795859	3074.999	258.686441	
90	10	108.7233164	18.19681	8.46863469	0.684	0.386467	-9260.76	337.0824641	
100	0	104.5346513	18.506003	9.4095941	0	0.058005	-6200.99	377.1011158	
								Sum	2.81661

Sample : F70/30 NM1

vm-heptane 146.5  
 $\delta$ m-heptane 15.5  
Mw 1755.562661  
vl 1581.809486  
 $\delta$ i 21.93902725  
den\_Toluene 867 g/l  
den\_Heptane 684 g/l

vm-toluene 106.228374  
 $\delta$ m-toluene 18.25  
R 8.314  
T 298  
Mw\_Tol. 92.14 g/mol  
Mw\_Hep. 100 g/mol

A 0.444797

Toluene (vol%)	Heptane (vol%)	vm	$\delta$ m	mol Toluene	mol Heptane	K	Solubility (g/l)	exp.Solubility (g/l)	error^2
0	100	146.5	15.5	0	6.84	1.88E+08	2.26E-05	0	5.09E-10
10	90	142.4728374	15.775	0.94095941	6.156	15599529	0.000282	0.072195015	0.005171
20	80	138.4456747	16.05	1.88191882	5.472	1400395	0.00326	0.143110643	0.019558
30	70	134.4185121	16.325	2.82287823	4.788	135922.4	0.03476	0.33601176	0.090752
40	60	130.3913495	16.6	3.76383764	4.104	14238.91	0.343042	0.953369048	0.372499
50	50	126.3641869	16.875	4.70479705	3.42	1606.77	3.140997	3.037218975	0.01077
60	40	122.3370242	17.15	5.64575646	2.736	194.8749	26.83811	11.34227021	
70	30	118.3098616	17.425	6.58671587	2.052	25.33865	220.3389	49.87938656	
80	20	114.282699	17.7	7.52767528	1.368	3.521935	2189.694	112.6581941	
90	10	110.2555363	17.975	8.46863469	0.684	0.521566	-11875.8	278.4321532	
100	0	106.2283737	18.25	9.4095941	0	0.08198	-6362.93	287.3688392	
								Sum	0.498751

## CURRICULUM VITAE

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