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APPENDICES

Appendix A Nomenclature

A	Cross-sectional area of the column perpendicular to the direction of the flow
AC	Asphaltene content
D	Diffusion coefficient
d_p	Mean particle size
J	Deposition flux
L	Bed length
m	Mass
Q	Volumetric flow rate
r	Radius of spherical particle
T	Absolute temperature
u	Superficial velocity
u_i	Interstitial velocity
ΔP	Pressure drop across the packed-bed
θ	Mass fraction
κ	Permeability
μ	Dynamic viscosity
ρ	Density of fluid
ϕ	Porosity

Appendix B Information of Heptane in Bow River Crude Oil Solution

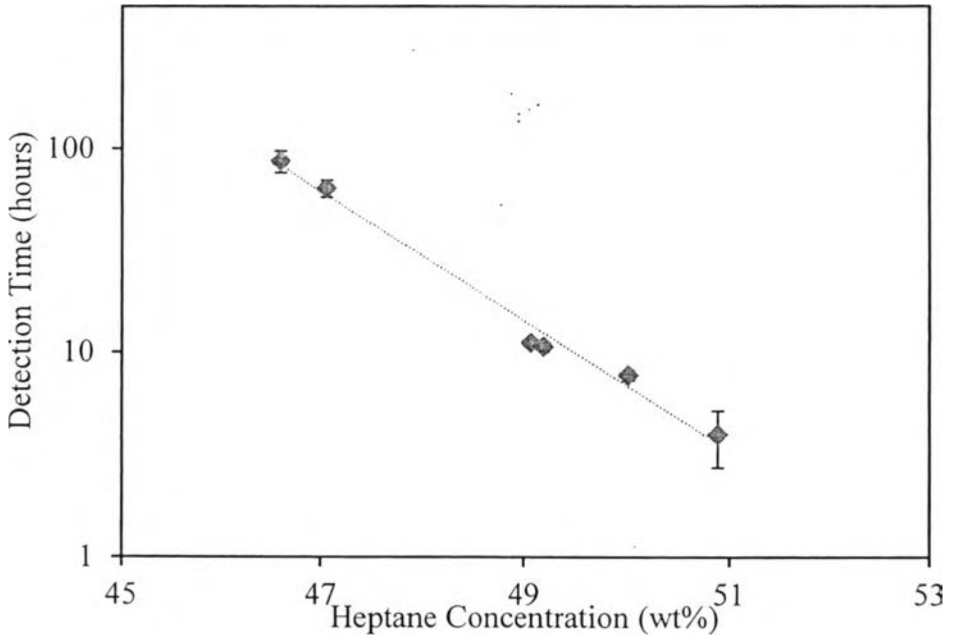

Figure B1 Detection time curve of Bow River crude oil as a function of heptane concentration.

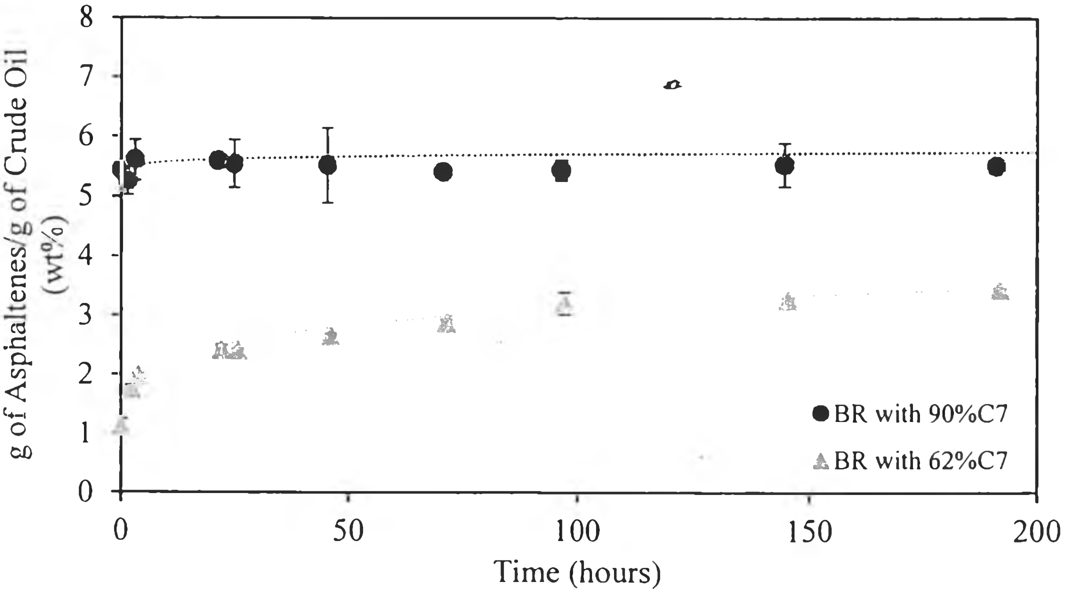

Figure B2 Asphaltene content of 62 wt% heptane in Bow River crude oil as a function of time from centrifugation experiment.

The heptane concentration of 62 wt% was chosen. At this condition, the heptane concentration was above the instantaneous asphaltenes detection point for maximizing the asphaltene content in solution in order to validate the apparatus. However, some asphaltenes that instantaneously precipitate out of the solution were centrifuged out to prevent the side effect of deposition from gravitation. Therefore, the asphaltene content at this condition was quantitatively measured.

Table B1 The composition of 62 wt% heptane in Bow River crude oil solution

Stable asphaltenes	0.95 wt%
Unstable asphaltenes	0.55 wt%
Maltenes	36.50 wt%
Heptane	62.00 wt%

Appendix C Information of Heptane in Athabasca Diluted Bitumen Solution

Figure C1 Detection time curve of Athabasca diluted bitumen as a function of heptane concentration.

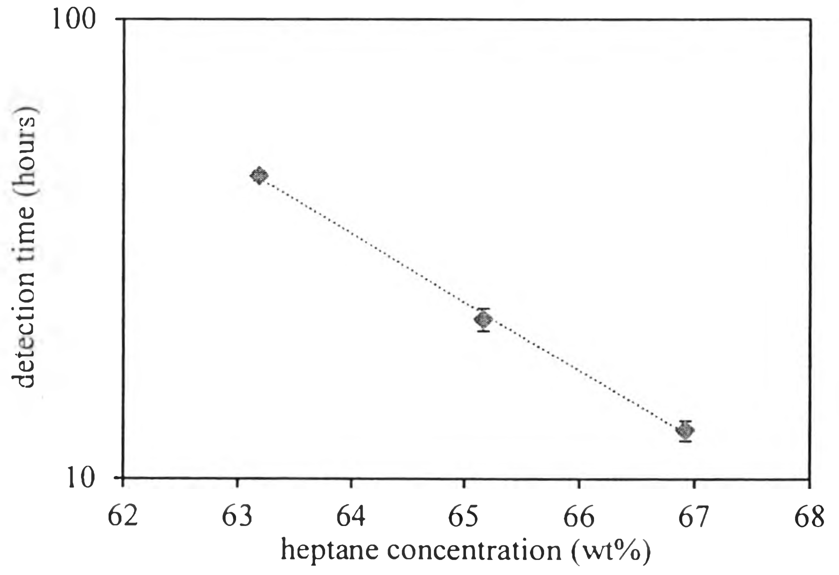

Figure C2 Asphaltene content of 67 wt% heptane in Athabasca diluted bitumen as a function of time from centrifugation experiment.

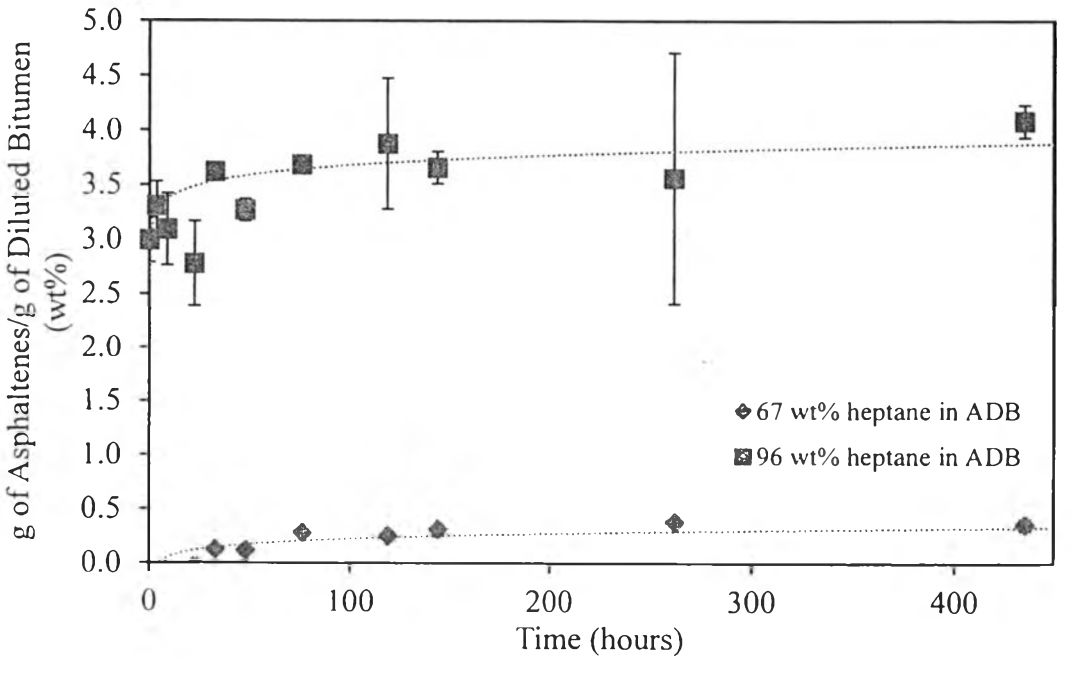

Table C1 The composition of 67 wt% heptane in Athabasca diluted bitumen solution

Stable asphaltenes	1.38 wt%
Unstable asphaltenes	0.14 wt%
Maltenes	36.48 wt%
Heptane	62.00 wt%

Appendix D Conditions and Information of Deposition Experiment

Table D1 Experimental conditions and information of 62 wt% heptane in Bow River crude oil solution

Average Heptane Conc.	T	Deposition Time	Residence Time	Re	Reservoir Asphaltene Depletion	Capture Efficiency
wt%	°C	hour	hour		%	%
62.65	25	0.07	0.1308	0.76	8.61	3.86
62.08	25	0.07	0.1319	0.76	8.61	3.86
62.31	25	0.05	0.1317	0.76	8.61	3.86
64.17	25	2.52	0.1256	0.76	8.61	3.86
61.95	25	3.07	0.1272	0.75	8.61	3.95
61.99	25	3.03	0.1319	0.67	8.61	4.42
62.07	25	6.03	0.1258	0.74	8.61	3.97
61.94	25	6.00	0.1233	0.77	8.61	3.81
61.99	25	6.07	0.1228	0.77	8.61	3.83
62.03	25	12.00	0.1150	0.81	8.61	3.63
62.41	25	12.00	0.1219	0.72	8.61	4.07
62.32	25	24.00	0.1275	0.74	8.61	4.00
62.16	25	24.00	0.1214	0.78	8.61	3.78
61.98	25	48.02	0.1211	0.70	8.61	4.18
62.17	25	48.03	0.1244	0.71	8.61	4.17
62.45	25	12.00	0.0175	4.84	15.86	1.11
62.68	25	12.00	0.0161	5.58	15.86	0.96
62.06	25	24.00	0.0153	5.52	15.86	0.97
62.04	25	24.18	0.0158	5.76	15.86	0.93
62.77	25	12.00	0.0125	6.70	15.49	0.79
62.04	25	12.00	0.0072	13.52	9.87	0.25
62.77	25	12.00	0.0047	17.28	7.51	0.15

Table D2 Experimental conditions and information of 67 wt% heptane in Athabasca diluted bitumen solution

Average Heptane Conc.	T	Deposition Time	Residence Time	Re	Reservoir Asphaltene Depletion	Capture Efficiency
wt%	°C	hour	hour		%	%
66.90	25	0.02	-	-	7.60	-
66.34	25	0.02	-	-	7.60	-
66.34	25	0.02	-	-	7.60	-
66.94	25	0.02	-	-	7.60	-
66.62	25	0.02	-	-	7.60	-
66.62	25	0.02	-	-	7.60	-
66.84	25	48.00	1.1925	0.02	7.60	9.27
66.92	25	48.00	1.0756	0.08	7.60	9.76
66.97	25	120.05	1.0647	0.08	7.60	9.17
67.00	25	120.12	1.0672	0.08	7.60	9.72
66.92	25	48.00	0.4258	0.24	19.20	8.05
67.01	25	48.00	0.3936	0.24	19.20	8.08
66.99	25	96.13	0.4228	0.24	19.20	8.06
66.99	25	31.22	0.1847	0.50	16.48	5.38
66.98	25	31.37	0.2072	0.49	16.48	5.41
66.96	25	48.03	0.2069	0.49	16.48	5.41
66.96	25	96.00	0.2094	0.49	16.48	5.45
66.96	25	48.00	0.1439	0.73	14.37	4.75
67.02	25	48.00	0.0094	10.94	15.21	0.34
67.00	25	48.00	0.0064	14.13	10.48	0.18

Appendix E Raw Data of Deposition Experiments

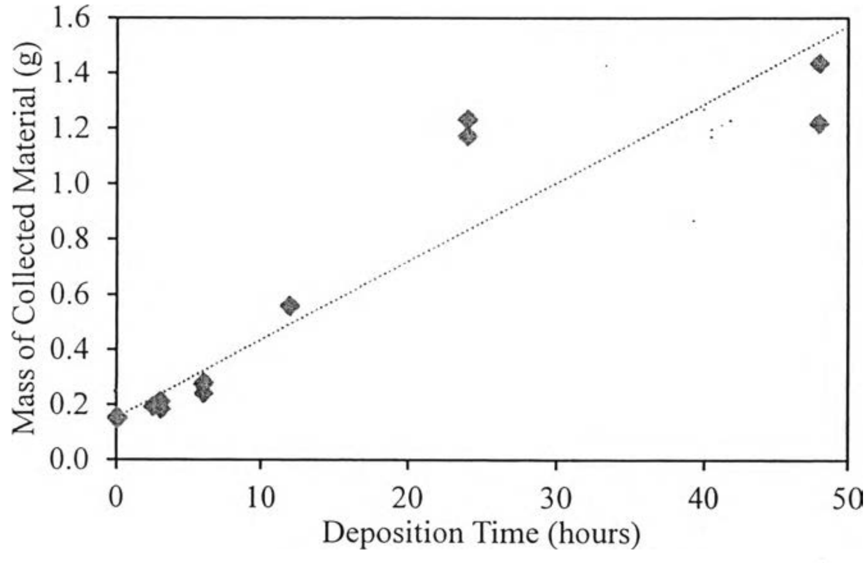

Figure E1 Mass of collected material as a function of deposition time for 62 wt% heptane in Bow River crude oil performed in apparatus 1 at a flow rate of 0.93 g/minute.

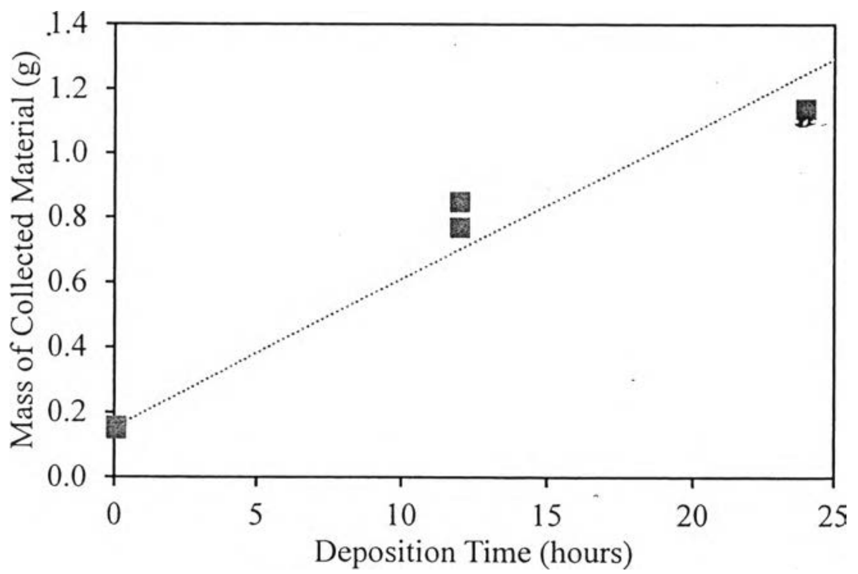

Figure E2 Mass of collected material as a function of deposition time for 62 wt% heptane in Bow River crude oil performed in apparatus 1 at a flow rate of 6.86 g/minute.

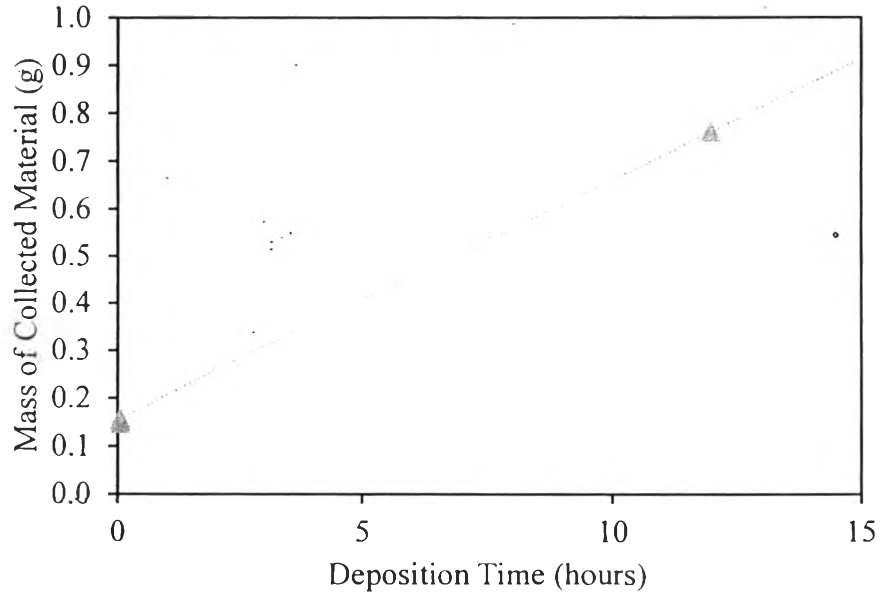

Figure E3 Mass of collected material as a function of deposition time for 62 wt% heptane in Bow River crude oil performed in apparatus 1 at a flow rate of 8.16 g/minute.

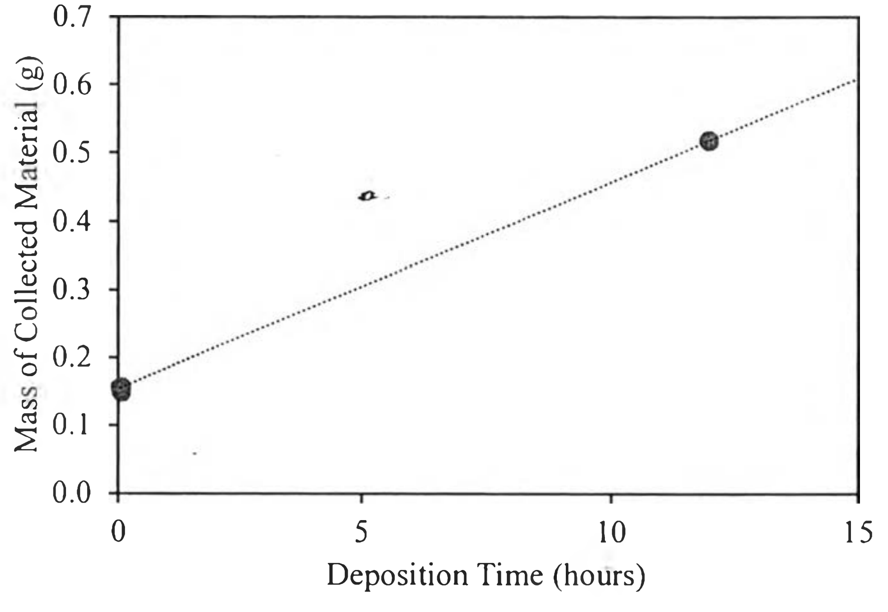

Figure E4 Mass of collected material as a function of deposition time for 62 wt% heptane in Bow River crude oil performed in apparatus 1 at a flow rate of 16.48 g/minute.

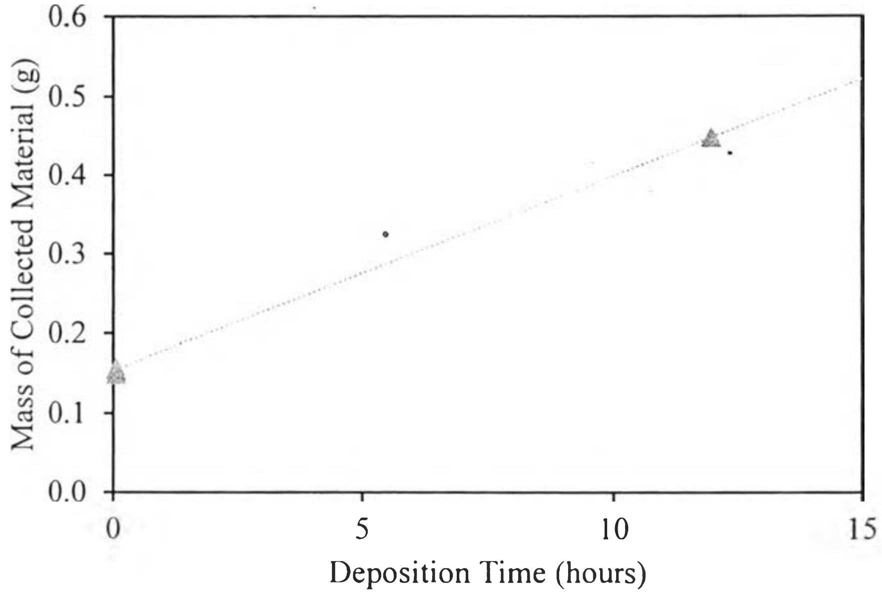

Figure E5 Mass of collected material as a function of deposition time for 62 wt% heptane in Bow River crude oil performed in apparatus 1 at a flow rate of 21.06 g/minute.

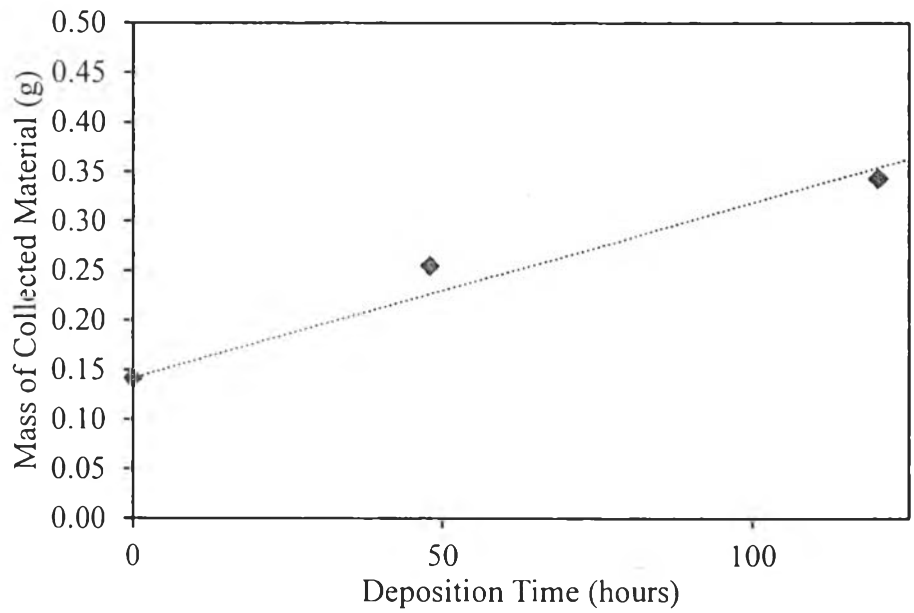

Figure E6 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 1 at a flow rate of 0.1 g/minute.

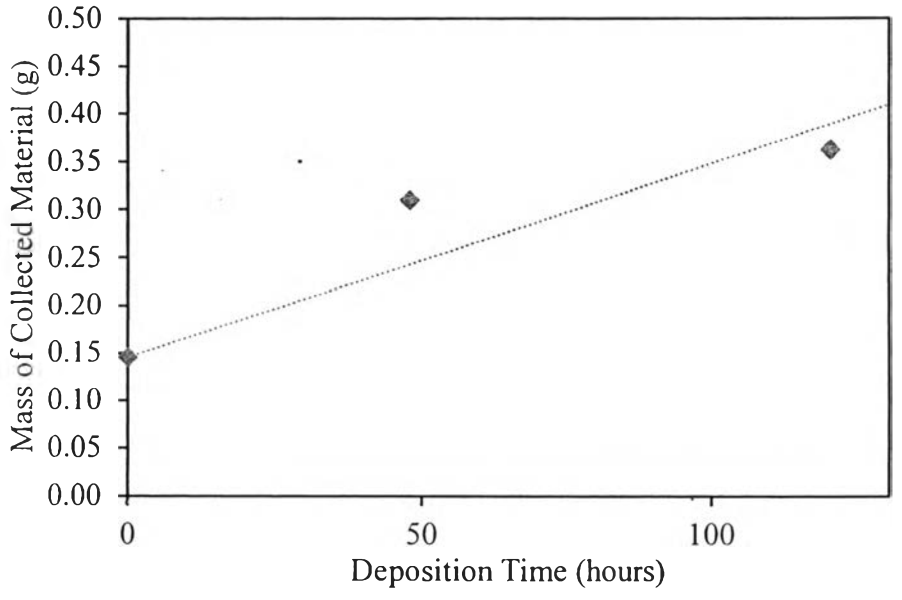

Figure E7 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 2 at a flow rate of 0.1 g/minute.

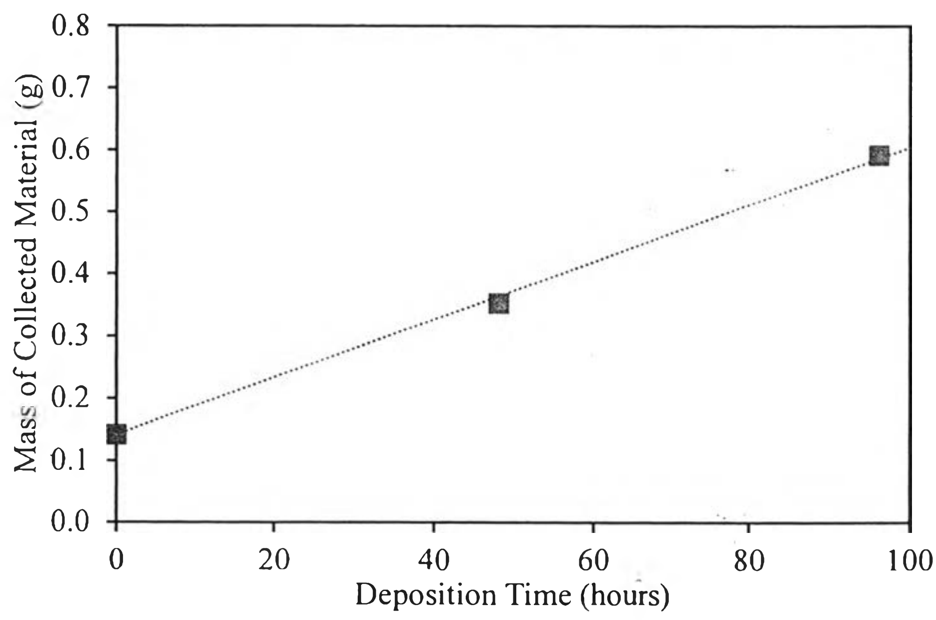

Figure E8 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 1 at a flow rate of 0.3 g/minute.

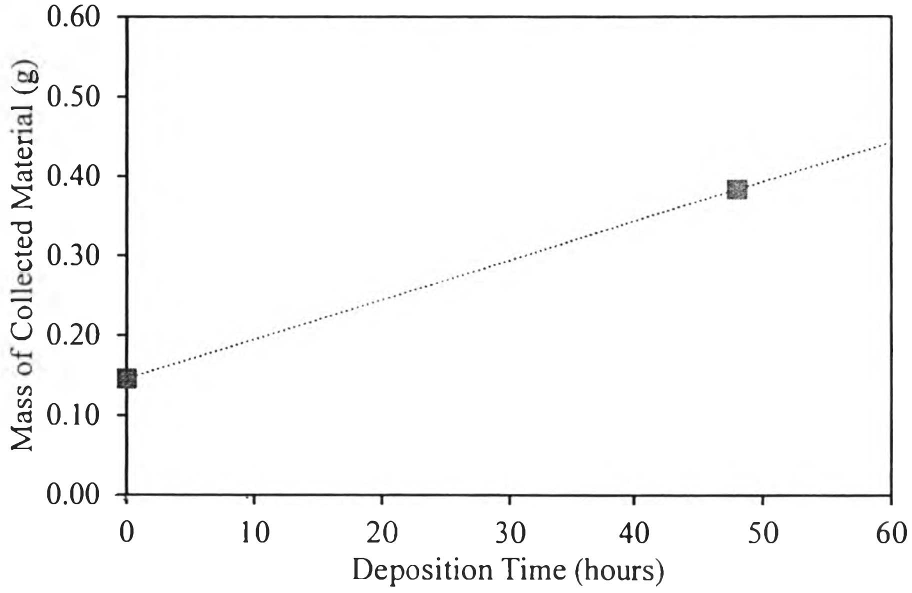

Figure E9 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 2 at a flow rate of 0.3 g/minute.

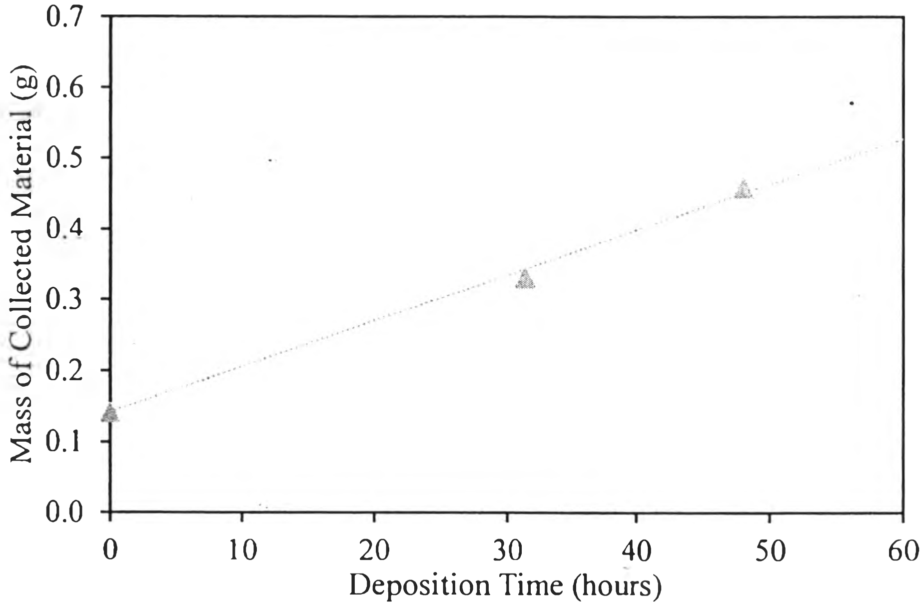

Figure E10 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 1 at a flow rate of 0.6 g/minute.

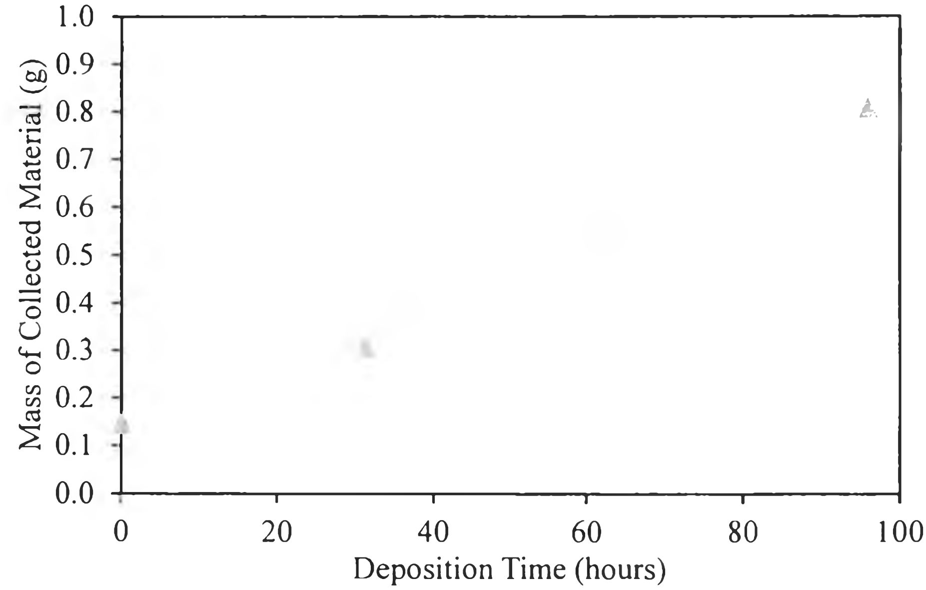

Figure E11 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 2 at a flow rate of 0.6 g/minute.

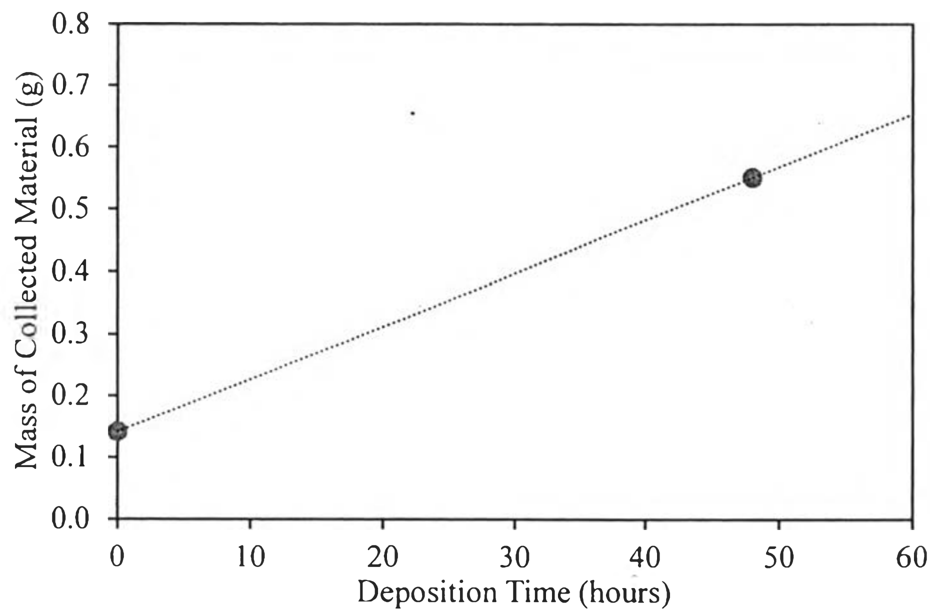

Figure E12 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 1 at a flow rate of 0.9 g/minute.

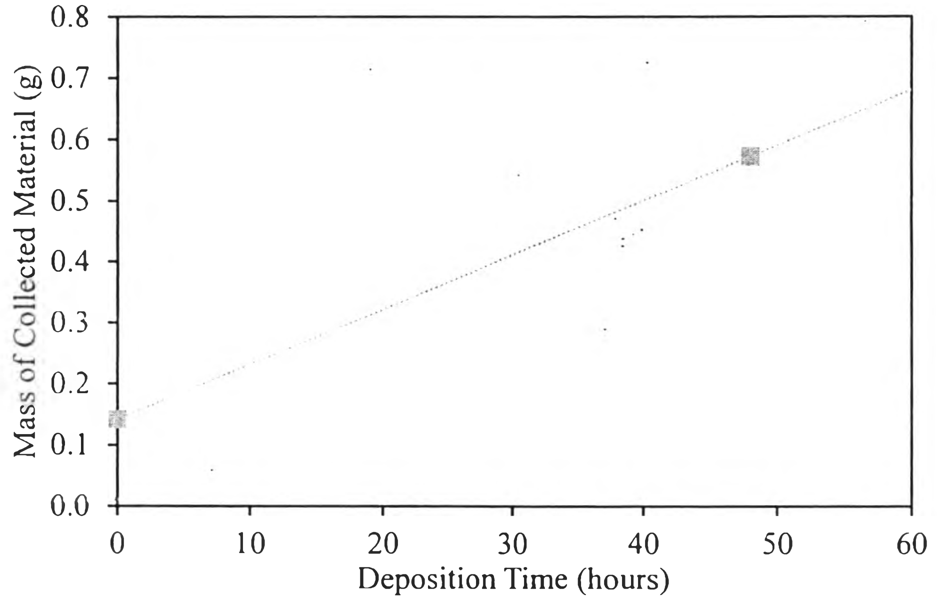

Figure E13 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 1 at a flow rate of 14 g/minute.

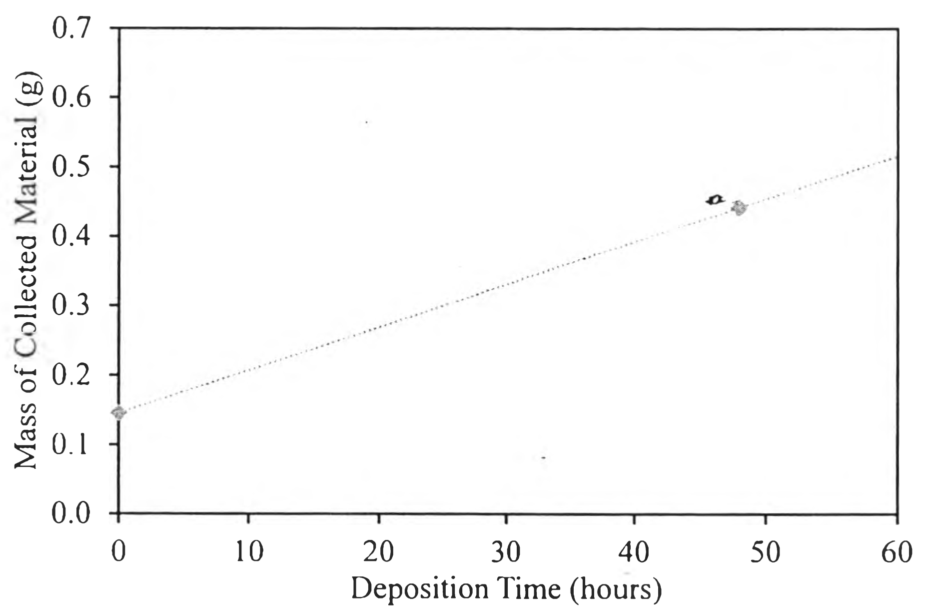

Figure E14 Mass of collected material as a function of deposition time for 67 wt% heptane in Athabasca diluted bitumen performed in apparatus 2 at a flow rate of 18 g/minute.

Appendix F Estimation of Critical Settling Diameter

Assuming the asphaltenes is the spherical particles, Stokes' law can be used to estimate the critical settling diameter of the asphaltene particle in a viscous solution at low Reynolds number. The assumptions of Stokes' law for behavior of particle in a fluid are as follow;

1) Laminar flow
2) Spherical particle
3) Homogeneous material
4) Smooth surfaces
5) Particle do not interfere with each other.

In case of fluid flow upward, the critical settling diameter can be estimated from the force balance between the drag force in the same direction with the flow and the gravitational force in the opposite direction of the flow. It is expressed by,

$$D = 2 \cdot \sqrt{\frac{9}{2}\frac{\mu v_s}{g(\rho_p - \rho_f)}} \tag{F.1}$$

where D is the critical settling diameter, μ is the dynamic viscosity, v_s is the settling velocity, g is the acceleration of gravity, ρ_p is the density of particle, and ρ_f is the density of fluid.

The higher the flow rate used to perform the experiments, the higher the critical settling diameter if consider the flow rate to be equal to the settling velocity. The density of asphaltenes were assumed to be 1200 kg/m^3. The density of BR-heptane solution was 755.5 kg/m^3 and the density of ADB-heptane solution was 745.6 kg/m^3.

Table F1 The critical settling diameter of asphaltene particle at various superficial velocity

62 wt% Heptane in Bow River Crude Oil		67 wt% Heptane in Athabasca Diluted Bitumen	
Superficial Velocity	Critical Settling Diameter	Superficial Velocity	Critical Settling Diameter
mm/s	micron	mm/s	micron
0.26	65.59	0.03	21.41
1.89	178.14	0.09	37.08
2.25	194.29	0.17	52.44
4.54	276.11	0.26	64.23
5.80	312.13	3.79	247.21
-	-	4.90	280.94

Appendix G Calculation of Asphaltene Content in Deposit

The mass fraction correlation was used to determine the asphaltene content of the deposit in the collected material. It is expressed as,

$$AC_{collected\ material} = \theta_{trapped\ liquid}AC_{trapped\ liquid} + \theta_{deposit}AC_{deposit} \quad (G.1)$$

The asphaltene content of the collected material was measured. The asphaltene content of the trapped liquid was also measured from the 1-minute experimental run time and it was held constant for all experiments. Afterward, the mass fraction of trapped liquid and deposit were obtained from the equation G.2, G.3, and G.4, respectively.

$$\theta_{trapped\ liquid} + \theta_{deposit} = 1 \quad (G.2)$$

$$\theta_{trapped\ liquid} = \frac{m_{trapped\ liquid}}{m_{collected\ material}} \quad (G.3)$$

$$\theta_{deposit} = \frac{m_{collected\ material} - m_{trapped\ liquid}}{m_{collected\ material}} \quad (G.4)$$

Hence, the asphaltene content of the deposit can be obtained by fitting the calculated asphaltene content of the deposit with the experimental data.

Appendix H Calculation of Diffusion Coefficient and Equivalent Diameter of Asphaltene Particle

The expanded form of Thoenes-Kramers correlation for flow through packed-bed is expressed by,

$$\left[\frac{k_c d_p}{D}\left(\frac{\emptyset}{1-\emptyset}\right)\frac{1}{\gamma}\right] = \left[\frac{U d_p \rho}{\mu(1-\emptyset)\gamma}\right]^{1/2}\left[\frac{\mu}{\rho D}\right]^{1/3} \quad \text{(H.1)}$$

where d_p = Particle diameter

k_c = Mass transfer coefficient

$\emptyset$ = Porosity

γ = Shape factor

U = Superficial velocity

μ = Viscosity

ρ = Fluid density

D = Diffusion coefficient

The diffusion coefficient was used as a fitting parameter to calculate the mass transfer coefficient. The calculated deposition flux was then obtained by assuming the asphaltene concentration at the surface was equal to zero. The adjusted diffusion coefficient that makes the calculation fit with the experimental data was then used to estimate the asphaltene particle size in the reservoir using Stokes-Einstein equation.

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Proceedings:

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