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ANNEXES

SAMPLES OF CALCULATION

In this part, the method of processing the data obtained from radioactive tracer method is illustrated. The data obtained comprise of a number of channels registered the radiation counts and radiation counts. Data obtained from both batch mixing and continuous mixing experiment were processed. Some of them are shown in Table A.1 for batch mixing experiment and in Table A.2 for continuous flow experiment.

The following is a brife explanation how those data were processed.

A.1 Data Preprocessing

For both batch mixing and continuous flow experiment all data were preprocessed as follows:

A.1.1 The registered channel and radiation counts were transfered to a computable programme (column A and column D respectively). In this work, Symphony release 2.0 was used.

A.1.2 The channels was converted to time (column B). Because the counting time was set at 0.5 second, so one channel increment corresponds to 0.5 second. And the time of injection was set to be zero (cell B1).

A.1.3 The middle time of each counting interval were selected to represent the time after injection (column C).

A.1.4 The mean value of a set of one hundred data of the radiation counts before the time of injection (these data were not shown here) was computed (cell D1) to represent the background radiation.

A.1.5 The radiation counts after the time of injection were corrected by both background corection to obtain net counts (column E), and decay correction (column F) to bring them back to the time of injection. For background correction, the counts was subtracted by the background. The decay correction was computed by using decay equation in Eq. (A.1)[16].

$$A_o = A \cdot e^{-\lambda t} \qquad (A.1)$$

$$\lambda = 0.693/t_{1/2}$$

where; A_o = counts at time of injection

A = counts at time t after injetion

λ = decay constant

t = time after injection

$t_{1/2}$ = hafe-life of radioactive material

A.2 Further data processing for batch mixing

For batch experiment, the preprocessed data were further processed as follows:

A.2.1 The mean and standard deviation of a set of one hundred data after injection 50 second was evalated (cell B206 and B207 recpectively) to set upper and lower limits.

A.2.2 All data were normalized by dividing with the mean (column G, H and I).

A.2.3 The upper limit, its mean plus 3 time of its standard deviation (cell B210), and the lower limit, its mean minus 3 time of its standard deviation (cell B 209) were computed. These limit were extended back to the time of injection (column H and I).

A.2.4 The shortest time that counts at that time and after was not exceed these limits was verified.

For another method of determining, the followings step had been done.

A.2.5 The standard deviation of a set of one handred data was calculated (column J) by moving average method[20]. The first set of data started from the time of injection (cell F1 to F100). Then the second set of data shifted to the next time, 0.5 second after injection (F2 to F101) and so on.

A.2.6 The shortest time that the standard deveation at that time and after was fairly constant was verified.

The formular of some cells in Table A.1 are shown below:

Cell	Formular
A25	+A24+1
B25	+B24+0.5
C25	+(B24+B25)/2
D25	2300 (entered by keyboard)
E25	+D25-$D$1
F25	(F0) +E25*(@EXP(0.6893/(6.02*60*60)*C25))
G25	(F2) +F25/$B$206
H25	(F2) +$C$209/$B$206
I25	(F2) +$C$210/$B$206
J25	@STD(F25..F214)*@SQRT(100/99)
B206	@AVG(F104..F203)
B207	@STD(F104..F203)
B208	+B206-3*B207
B209	+B206+3*B207

A.3 Further data processing for continuous flow

For continuous mixing experiment, the preprocessed data were further processed as follows:

A.3.1 The ·corrected counts were normalized by diviidng with the maximum counts(column G).

A.3.2 The the product of time, normalized corrected counts at that time and counting time interval was calculated (column H) starting from the time of injection.

A.3.3 The product of normalized corrected count and counting time interval was calculated (column I).

A.3.4 The residence time was calculated (D250) Using Eq. (A.2)[21] (by dividing the sum of product obtained in (A.3.2) by the product obtained in (A.3.3).

$$t = \int \frac{C \cdot tdt}{Cdt} \qquad (A.2)$$

where ; C = normalized corrected counts

t = time

dt = counting time interval

The formular of some cells in Table A.2 are shown below:

Cell	Formular
A25	+A24+1
B25	+B24+0.5
C25	+(B24+B25)/2
D25	46 (entered by keyboard)
E25	+D25-$D$1
F25	(F0) +E25*(@EXP(0.6893/(6.02*60*60)*C25))
G25	(F3) +F25/@MAX($F$1..$F$214)
H25	(F2) +F25*C25*(C25-C24)
I25	(F2) +F25*(C25-C24)
D250	(F2) @SUM(H1..H214)/@SUM(I1..I214)

Table A.1 Analyzed data from a batch experiment

	A	B	C	D	E	F	G	H	I	J
	Channel Number	Time after Injection (sec.)	Middle Time (sec.)	counts	Background Corrected	Decay Corrected	Normalized counts	Upper Limit	Lower Limit	Standard Deviation
1	156	0		71	0	0	0.00	0.95	1.05	925.39
2	157	0.5	0.25	102	28	28	0.01	0.95	1.05	891.87
3	158	1	0.75	1297	1223	1223	0.53	0.95	1.05	863.43
4	159	1.5	1.25	2505	2431	2431	1.06	0.95	1.05	855.54
5	160	2	1.75	8691	8620	8620	3.75	0.95	1.05	855.54
6	161	2.5	2.25	7881	7807	7808	3.39	0.95	1.05	579.62
7	162	3	2.75	3683	3609	3609	1.57	0.95	1.05	172.02
8	163	3.5	3.25	2376	2302	2302	1.00	0.95	1.05	106.62
9	164	4	3.75	2068	1994	1994	0.87	0.95	1.05	106.91
10	165	4.5	4.25	2029	1955	1955	0.85	0.95	1.05	103.57
11	166	5	4.75	1873	1799	1799	0.78	0.95	1.05	99.41
12	167	5.5	5.25	1806	1812	1812	0.79	0.95	1.05	87.51
13	168	6	5.75	2013	1939	1939	0.84	0.95	1.05	74.56
14	169	6.5	6.25	2003	1929	1929	0.84	0.95	1.05	66.87
15	170	7	6.75	2161	2090	2090	0.91	0.95	1.05	56.75
16	171	7.5	7.25	2250	2176	2177	0.95	0.95	1.05	53.26
17	172	8	7.75	2218	2144	2145	0.93	0.95	1.05	52.16
18	173	8.5	8.25	2250	2176	2177	0.95	0.95	1.05	50.16
19	174	9	8.75	2279	2205	2206	0.96	0.95	1.05	48.88
20	175	9.5	9.25	2321	2250	2251	0.98	0.95	1.05	48.14
21	176	10	9.75	2331	2260	2261	0.98	0.95	1.05	48.04
22	177	10.5	10.25	2421	2350	2351	1.02	0.95	1.05	48.72
23	178	11	10.75	2316	2242	2243	0.97	0.95	1.05	48.40
24	179	11.5	11.25	2354	2280	2281	0.99	0.95	1.05	48.33
25	180	12	11.75	2300	2226	2227	0.97	0.95	1.05	48.31
⋮	⋮	⋮	⋮	⋮	⋮	⋮				
181	336	90	89.75	2368	2294	2301				
182	337	90.5	90.25	2341	2267	2274				
183	338	91	90.75	2427	2353	2360				
184	339	91.5	91.25	2364	2290	2297				
185	340	92	91.75	2339	2265	2272				
186	341	92.5	92.25	2402	2328	2335				
187	342	93	92.75	2390	2316	2323				
188	343	93.5	93.25	2380	2306	2313				
189	344	94	93.75	2339	2265	2272				
190	345	94.5	94.25	2372	2298	2305				
191	346	95	94.75	2313	2239	2246				
192	347	95.5	95.25	2379	2305	2312				
193	348	96	95.75	2406	2332	2339				
194	349	96.5	96.25	2283	2209	2216				
195	350	97	96.75	2313	2239	2246				
196	351	97.5	97.25	2329	2255	2262				
197	352	98	97.75	2423	2349	2356				
198	353	98.5	98.25	2360	2286	2293				
199	354	99	98.75	2369	2295	2302				
200	355	99.5	99.25	2336	2262	2269				
201	356	100	99.75	2331	2260	2267				

206	MEAN	2300.83	
207	STANDARD	41.31	
208	DIVIATION		
209	LOWER LIMIT	0.95	(2177)
210	UPPER LIMIT	1.05	(2425)

Table A.2 Analyzed data from a continuous experiment

	A	B	C	D	E	F	G	H	I
	Channel Number	Time after Injection (sec.)	Middle Time (sec.)	counts	Background Corrected	Decay Corrected	Normalized counts	C*t*dt	C*dt
1	256	0		32	0	0	0.000	0.00	0.000
2	257	0.5	0.25	38	6	6	0.005	0.38	1.500
3	258	1	0.75	33	1	1	0.001	0.38	0.500
4	259	1.5	1.25	37	5	5	0.005	3.13	2.500
5	260	2	1.75	33	1	1	0.001	0.88	0.500
6	261	2.5	2.25	34	2	2	0.002	2.25	1.000
7	262	3	2.75	35	3	3	0.003	4.13	1.500
8	263	3.5	3.25	60	28	28	0.025	45.50	14.001
9	264	4	3.75	52	20	20	0.018	37.50	10.001
10	265	4.5	4.25	35	3	3	0.003	6.38	1.500
11	266	5	4.75	27	-5	-5	-0.005	-11.88	-2.500
12	267	5.5	5.25	41	9	9	0.008	23.63	4.501
13	268	6	5.75	27	-5	-5	-0.005	-14.38	2.500
14	269	6.5	6.25	39	7	7	0.006	21.88	3.501
15	270	7	6.75	45	13	13	0.012	43.88	6.501
16	271	7.5	7.25	34	2	2	0.002	7.25	1.000
17	272	8	7.75	38	6	6	0.005	23.26	3.001
18	273	8.5	8.25	35	3	3	0.003	12.38	1.500
19	274	9	8.75	40	8	8	0.007	35.01	4.001
20	275	9.5	9.25	38	6	6	0.005	27.76	3.001
21	276	10	9.75	46	14	14	0.013	68.27	7.002
22	277	10.5	10.25	48	16	16	0.014	82.03	8.003
23	278	11	10.75	39	7	7	0.006	37.64	3.501
24	279	11.5	11.25	29	-3	-3	-0.003	-16.88	-1.501
25	280	12	11.75	46	14	14	0.013	82.28	7.003
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
187	442	93	92.75	35	3	3	0.003	139.54	1.504
188	443	93.5	93.25	38	6	6	0.005	280.59	3.009
189	444	94	93.75	35	3	3	0.003	141.05	1.505
190	445	94.5	94.25	42	10	10	0.009	472.67	5.015
191	446	95	94.75	40	8	8	0.007	380.15	4.012
192	447	95.5	95.25	51	19	19	0.017	907.64	9.529
193	448	96	95.75	33	1	1	0.001	48.02	0.502
194	449	96.5	96.25	39	7	7	0.006	337.91	3.511
195	450	97	96.75	37	5	5	0.005	242.62	2.508
196	451	97.5	97.25	48	16	16	0.014	780.42	8.025
197	452	98	97.75	40	8	8	0.007	392.22	4.013
198	453	98.5	98.25	49	17	17	0.015	837.75	8.527
199	454	99	98.75	47	15	15	0.014	742.97	7.524
200	455	99.5	99.25	28	-4	-4	-0.004	-199.13	-2.006
201	456	100	99.75	33	1	1	0.001	50.03	0.502
202	457	100.5	100.25	46	14	14	0.013	704.00	7.022
203	458	101	100.75	30	-2	-2	-0.002	-101.08	-1.003
204	459	101.5	101.25	38	6	6	0.005	304.74	3.010
205	460	102	101.75	35	3	3	0.003	153.12	1.505
206	461	102.5	102.25	37	5	5	0.005	256.46	2.503

250 MEAN RESIDENCE TIME 46.97 SEC.

AUTOBIOGRAPHY

Pipop Thamtharai was born on January 27, 1958 in Bangkok, Thailand. He received his Bachelor of Science Degree in Chemical Engineering from Chulalongkorn University, Bangkok, Thailand, in 1980. He has worked at Office of Atomic Energy for Peace, Ministry of Science Technology and Energy since 1980.