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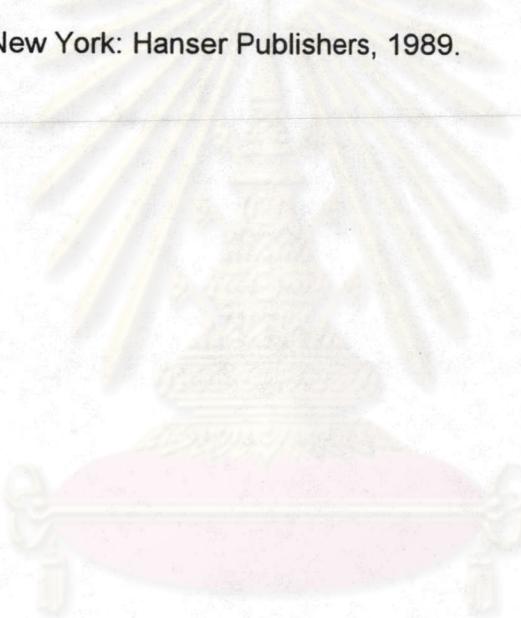
Appendix

A1. Specification of equipment

A1.1 Continuous kneader

Model	S1 Type
Maker	Kurimoto Co., Ltd.
Paddle dimension	25 D x 255 L mm. (L/D = 10.2)
Paddle speed	81 ~ 324 rpm(Variable) at 50 Hz.
	96 ~ 384 rpm(Variable) at 60 Hz.
Barrel heating, cooling system	
Heating system	Band heater (electric cap. 1.5 kW)
Cooling system	Water
Drive unit	Variable speed reducer (with motor)
	Type : AIV SS25D-10R 0.4-4
	Motor : 0.4 kW x 4P T.E.F.C. Type
Power source	A.C. 200/220 V. 50/60 Hz. 3ϕ
Power consumption	1.9 kW (Motor 0.4 kW + Heater 1.5 kW)
Capacity	approx. 2 kg/hr
Material of main parts	
Barrel	SUS 316 + WC
Screw & paddle	CIX
Main shaft	SUS 630
Size	540 mm(W) x 1100 mm(L) x 1260 mm(H)
Weight	Approx. 150 kg

A.1.2 Accurate feeder

Model	102 Type
Maker	Kurimoto Co., Ltd.
Electrical requirement	110 Volt., 60 cycle A.C. , single phase
Motor	
A.C.	1/25 HP.
D.C.	1/20 HP. 24 Volt DC, Gear motor, 45 rpm output
Control	
A.C.	Direct A.C. Control
D.C.	KB Electronics Circuit Board with : 20:1 Speed range Adjustable current limit
Feed rates	Approx. 8.496×10^{-5} to 28.32 liter/hr using stainless steel screws 0.75 inch. dia. with center core helix.
Contact material	
Hopper	0.094 inch. thick flexible PVC
Helix	stainless steel
Discharge nozzle	stainless steel
Non-contact material	304 Stainless steel frame and side panels
Dimensions	215 mm(W) x 314 mm(L) x 200 mm(H)
Capacity	Max. 18 liter/hr
Weight	6.5 kg

A1.3 Mold temperature controller

Model	MC III -15 H Type
Maker	Kurimoto Co., Ltd.
Power supply	A.C. 3 ϕ 200/220 V 50/60 Hz.
Medium	Clean water (soft water)
Operational temperature range	140 $^\circ$F ~ 248 $^\circ$F 60 $^\circ$C ~ 120 $^\circ$C
Pump motor	250 W, 4P
Heater : capacity	3 kW

Heater box
    Material
    Capacity
	
	 SUS 304
	 3.5 liter

Temperature controller
    Operation
    Input (Thermocouple)
    Setting/indication
    Timer function
 	
    Alarm
	
	 Heating or cooling PID action
	 K (CA)
	 Digital setting and indication
	 Setting range of 0 to 99.9 hr (0.1 hr - 6 min.). Operation starts when the timer has run out.
	 Drop in medium level, abnormal temperature rise, pump overload, power supply phase reversal, broken wire in the sensor, and upper and lower limit alarm

Water level detection	Float switch
Pressure gauge	ϕ 50 x 6 kg$_f$/cm^2
External dimensions	232 mm(W) x 506 mm(D) x 538 mm(H)
Unit weight	Approx. 50 Kg.
Power consumption	3.25 kW

A1.4 Press roller

Model	ϕ 90 x 200 L
Maker	Kurimoto Co., Ltd.
Size	600 mm(W) x 920 mm(L) x 894 mm(H)
Roller speed	0 - 10 rpm.
Weight	Approx. 100 kg
Power consumption	0.2 kW
Voltage and phase	200/220 V, 50/60 Hz., 3 phase
Capacity	Approx. 2 kg/hr.

A2. Experimental data

A2.1 Calibration data of accurate feeder flow (for HDPE powder used)

Potentiometer Setting	Feed rate (g/min)
100	9.25
200	19.86
300	29.99
400	41.25
500	51.15
600	61.07
700	71.90
800	82.01
900	92.48

A2.2 Calibration curve of accurate feeder (HDPE powder)
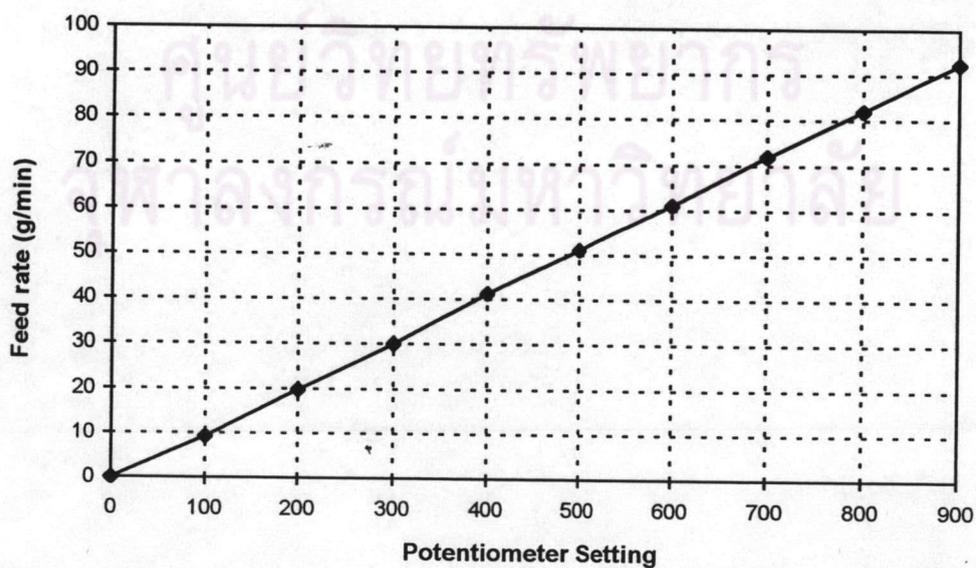
A2.3   Calibration data of rotational speed of screw

Potentiometer Setting	Rotational speed (rpm)
81	89
101.5	112.8
122	132.5
142	155.5
162	177.6
202.5	221.7
243	268.7
283.5	313.4
324	353.8

A2.4   Calibration curve of rotational speed of screw
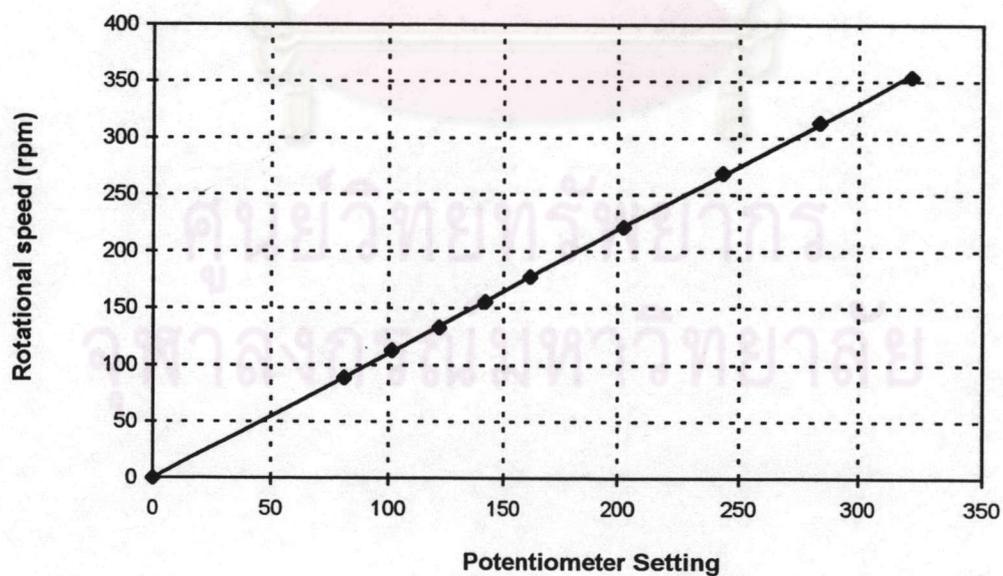
A2.5 The actual experimental data

A2.5.1 Carbon black

1) Condition : Kneading temperature = 200 °C
Speed of screw = 162 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	24	25
8	0.125	52	51	54	49
10	0.1	67	66	63	59
16	0.0625	106	109	107	110
20	0.05	153	152	150	149
40	0.025	332	305	309	312
80	0.0125	642	658	659	671
Sample size		200	197	201	202

2) Condition : Kneading temperature = 200 °C
Speed of screw = 162 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	58	55	58	59
10	0.1	90	90	89	85
16	0.0625	170	136	134	137
20	0.05	190	163	170	166
40	0.025	411	360	384	380
80	0.0125	879	924	849	834
Sample size		195	192	187	185

3) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	23	25
8	0.125	47	50	49	50
10	0.1	65	66	66	70
16	0.0625	149	151	149	148
20	0.05	188	192	194	199
40	0.025	427	444	427	419
80	0.0125	1000	997	1040	987
Sample size		159	177	154	171

4) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	24	25	25
8	0.125	52	52	54	55
10	0.1	59	63	61	69
16	0.0625	139	140	138	138
20	0.05	167	172	164	148
40	0.025	363	376	337	342
80	0.0125	746	755	765	769
Sample size		189	190	180	185

5) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	62	60	61
10	0.1	89	90	91	87
16	0.0625	147	151	157	160
20	0.05	231	235	241	235
40	0.025	224	265	260	265
80	0.0125	663	698	690	700
Sample size		179	192	184	187

6) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	24	25
8	0.125	60	59	57	50
10	0.1	84	83	76	70
16	0.0625	145	150	136	126
20	0.05	183	166	181	162
40	0.025	371	363	369	335
80	0.0125	881	849	907	795
Sample size		177	178	180	182

7) Condition : Kneading temperature = 200 °C
Speed of screw = 162 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	54	55	53	55
10	0.1	80	84	83	82
16	0.0625	154	150	146	146
20	0.05	190	186	185	186
40	0.025	384	364	359	363
80	0.0125	849	808	774	776
Sample size		187	197	189	190

8) Condition : Kneading temperature = 200°C
Speed of screw = 162 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	55	61	58	60
10	0.1	79	80	83	81
16	0.0625	140	148	145	148
20	0.05	175	192	195	197
40	0.025	397	426	449	437
80	0.0125	961	1001	1086	1071
Sample size		197	191	214	195

9) Condition : Kneading temperature = 200 °C
   Speed of screw = 243 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	25	24
8	0.125	57	51	56	56
10	0.1	71	72	70	73
16	0.0625	136	140	142	131
20	0.05	196	166	165	149
40	0.025	389	340	349	310
80	0.0125	880	762	805	725
Sample size		150	147	149	152

10) Condition : Kneading temperature = 200 °C
    Speed of screw = 243 rpm
    Feed rate = 51.2 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	25	25
8	0.125	51	55	54	49
10	0.1	73	70	74	71
16	0.0625	138	130	137	134
20	0.05	161	168	181	165
40	0.025	348	336	375	373
80	0.0125	793	803	939	920
Sample size		162	177	167	171

11) Condition : Kneading temperature = 200 °C
   Speed of screw = 243 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	61	62	63	60
10	0.1	92	90	93	87
16	0.0625	171	173	180	185
20	0.05	237	255	249	241
40	0.025	390	364	374	376
80	0.0125	873	868	858	866
Sample size		174	175	185	189

12) Condition : Kneading temperature = 200 °C
   Speed of screw = 243 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	24	25
8	0.125	58	60	58	58
10	0.1	73	71	74	72
16	0.0625	149	150	146	149
20	0.05	155	179	196	180
40	0.025	326	366	378	370
80	0.0125	807	827	854	790
Sample size		190	193	189	187

13) Condition : Kneading temperature = 200 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	24	25
8	0.125	47	50	49	46
10	0.1	84	81	83	83
16	0.0625	141	155	146	147
20	0.05	200	199	194	198
40	0.025	395	380	366	378
80	0.0125	858	822	810	820
Sample size		150	147	149	152

14) Condition : Kneading temperature = 200 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	24
8	0.125	54	57	56	59
10	0.1	72	77	77	74
16	0.0625	113	125	124	124
20	0.05	139	168	167	159
40	0.025	232	330	322	311
80	0.0125	516	728	720	690
Sample size		143	173	161	159

15) Condition : Kneading temperature = 200°C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	62	59	59
10	0.1	86	87	85	83
16	0.0625	150	171	161	145
20	0.05	206	212	191	191
40	0.025	395	436	387	391
80	0.0125	906	990	864	889
Sample size		170	172	169	170

16) Condition : Kneading temperature = 200 °C
Speed of screw = 324 rpm
Feed rate = 71.9 g/min
Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	61	62	60	61
10	0.1	92	88	89	91
16	0.0625	184	191	190	190
20	0.05	269	263	267	260
40	0.025	375	387	380	379
80	0.0125	770	831	829	831
Sample size		192	174	185	187

17) Condition : Kneading temperature = 200 °C
   Speed of screw = 324 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	63	61	60	62
10	0.1	95	89	92	95
16	0.0625	175	179	183	187
20	0.05	304	311	307	314
40	0.025	451	401	424	437
80	0.0125	927	861	900	930
Sample size		201	174	180	183

18) Condition : Kneading temperature = 200 °C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	59	60	62	59
10	0.1	80	85	82	89
16	0.0625	158	153	164	177
20	0.05	194	184	194	202
40	0.025	415	370	396	429
80	0.0125	967	901	919	1043
Sample size		183	165	174	175

19) Condition : Kneading temperature = 200°C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	24	25	24
8	0.125	52	45	60	54
10	0.1	68	58	82	70
16	0.0625	100	84	130	114
20	0.05	143	112	158	142
40	0.025	262	209	320	290
80	0.0125	620	481	676	632
Sample size		169	194	174	181

20) Condition : Kneading temperature = 200°C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	59	57	58	58
10	0.1	83	81	84	83
16	0.0625	152	148	169	149
20	0.05	190	187	211	184
40	0.025	422	409	464	381
80	0.0125	981	994	1130	928
Sample size		200	204	209	190

21) Condition : Kneading temperature = 240 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	59	59	60
10	0.1	81	80	82	79
16	0.0625	156	155	139	152
20	0.05	204	206	189	201
40	0.025	429	403	406	410
80	0.0125	1021	877	938	951
Sample size		145	159	148	152

22) Condition : Kneading temperature = 220 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	24	25
8	0.125	63	63	62	64
10	0.1	91	94	92	95
16	0.0625	240	239	242	249
20	0.05	181	181	178	180
40	0.025	357	386	372	381
80	0.0125	829	866	834	837
Sample size		170	171	168	170

23) Condition : Kneading temperature = 240 $^{\circ}$C
    Speed of screw = 162 rpm
    Feed rate = 92.5 g/min
    Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	51	57	55	57
10	0.1	70	75	74	78
16	0.0625	120	125	126	131
20	0.05	143	153	146	173
40	0.025	316	334	317	327
80	0.0125	778	790	691	727
Sample size		183	179	177	181

24) Condition : Kneading temperature = 240 $^{\circ}$C
    Speed of screw = 162 rpm
    Feed rate = 92.5 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	57	57	57
10	0.1	75	83	79	77
16	0.0625	137	152	125	130
20	0.05	165	176	162	164
40	0.025	363	354	329	335
80	0.0125	824	805	796	799
Sample size		171	169	167	170

25) Condition : Kneading temperature = 240 °C
Speed of screw = 162 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	61	63	62
10	0.1	94	92	90	91
16	0.0625	179	182	180	179
20	0.05	217	200	194	201
40	0.025	362	342	324	363
80	0.0125	797	736	723	798
Sample size		150	147	154	151

26) Condition : Kneading temperature = 220 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	24	24	25
8	0.125	61	60	60	61
10	0.1	85	84	84	85
16	0.0625	156	165	170	171
20	0.05	219	215	221	225
40	0.025	440	455	452	444
80	0.0125	887	897	909	890
Sample size		178	175	185	179

27) Condition : Kneading temperature = 220°C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	25	25
8	0.125	55	61	60	60
10	0.1	78	83	78	77
16	0.0625	144	156	156	156
20	0.05	181	213	187	180
40	0.025	391	400	409	400
80	0.0125	968	870	865	807
Sample size		190	177	184	175

28) Condition : Kneading temperature = 220 °C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	24	25
8	0.125	57	59	54	59
10	0.1	75	77	79	79
16	0.0625	135	131	135	135
20	0.05	166	167	182	155
40	0.025	340	337	316	355
80	0.0125	794	785	713	820
Sample size		192	201	200	207

29) Condition : Kneading temperature = 240 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	59	57	61
10	0.1	87	91	89	90
16	0.0625	150	151	153	152
20	0.05	258	259	249	254
40	0.025	422	398	376	358
80	0.0125	696	646	581	630
Sample size		154	167	161	159

30) Condition : Kneading temperature = 240 °C
   Speed of screw = 162rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	56	55	57	57
10	0.1	74	71	78	77
16	0.0625	116	120	127	122
20	0.05	142	147	147	147
40	0.025	305	305	316	310
80	0.0125	657	674	708	699
Sample size		159	175	177	173

31) Condition : Kneading temperature = 240 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	24	25
8	0.125	55	50	47	49
10	0.1	75	71	82	69
16	0.0625	149	150	138	138
20	0.05	177	192	174	158
40	0.025	363	386	337	342
80	0.0125	848	856	765	771
Sample size		178	183	179	180

32) Condition : Kneading temperature = 240 °C
   Speed of screw = 162 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	61	60	62
10	0.1	90	92	89	91
16	0.0625	195	194	190	191
20	0.05	253	259	265	260
40	0.025	365	362	393	367
80	0.0125	815	840	798	829
Sample size		199	203	200	201

33) Condition : Kneading temperature = 240 °C
Speed of screw = 162 rpm
Feed rate = 71.9 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	24	25
8	0.125	60	61	61	62
10	0.1	89	92	90	91
16	0.0625	189	183	179	185
20	0.05	237	247	239	241
40	0.025	407	411	409	410
80	0.0125	890	918	940	917
Sample size		189	192	200	180

34) Condition : Kneading temperature = 240°C
Speed of screw = 162 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	57	61	60
10	0.1	84	89	88	84
16	0.0625	154	155	157	151
20	0.05	199	187	197	186
40	0.025	407	387	421	393
80	0.0125	946	891	989	892
Sample size		190	178	202	187

35) Condition : Kneading temperature = 240°C
Speed of screw = 162 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	24	25	24
8	0.125	60	61	55	60
10	0.1	82	87	79	85
16	0.0625	156	143	124	150
20	0.05	195	196	153	190
40	0.025	398	393	336	392
80	0.0125	880	843	800	870
Sample size		167	174	170	169

36) Condition : Kneading temperature = 240 °C
Speed of screw = 162 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	25	25
8	0.125	58	57	55	54
10	0.1	80	76	75	73
16	0.0625	151	138	142	138
20	0.05	187	179	174	179
40	0.025	406	378	374	360
80	0.0125	968	870	865	807
Sample size		185	191	184	200

37) Condition : Kneading temperature = 240 °C
   Speed of screw = 243 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	24	25
8	0.125	60	61	60	61
10	0.1	85	83	87	84
16	0.0625	190	183	187	191
20	0.05	287	273	291	274
40	0.025	362	342	324	363
80	0.0125	797	736	723	798
Sample size		147	150	155	149

38) Condition : Kneading temperature = 240 °C
   Speed of screw = 243 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	64	62	61	62
10	0.1	88	89	94	90
16	0.0625	192	187	183	175
20	0.05	283	290	287	277
40	0.025	514	433	480	476
80	0.0125	1160	971	1090	1100
Sample size		180	181	185	174

39) Condition : Kneading temperature = 240 °C
   Speed of screw = 243 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	58	50	60
10	0.1	81	85	76	83
16	0.0625	177	180	189	192
20	0.05	274	280	287	280
40	0.025	326	344	291	330
80	0.0125	754	730	667	750
Sample size		190	197	184	191

40) Condition : Kneading temperature = 240 °C
   Speed of screw = 243 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	56	56	56
10	0.1	84	76	80	82
16	0.0625	207	210	207	202
20	0.05	300	299	297	307
40	0.025	321	271	304	314
80	0.0125	752	652	711	745
Sample size		225	210	227	199

41) Condition : Kneading temperature = 240 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	61	61	58	57
10	0.1	87	87	84	79
16	0.0625	154	157	157	129
20	0.05	204	198	196	177
40	0.025	404	402	388	347
80	0.0125	927	895	862	795
Sample size		189	188	190	190

42) Condition : Kneading temperature = 240 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	24	25	25
8	0.125	56	60	57	58
10	0.1	77	79	78	77
16	0.0625	132	145	137	135
20	0.05	164	171	169	170
40	0.025	335	341	339	340
80	0.0125	771	781	778	779
Sample size		171	164	165	184

43) Condition : Kneading temperature = 240°C
   Speed of screw = 324 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	60	58	58
10	0.1	83	85	81	83
16	0.0625	160	150	149	153
20	0.05	198	209	180	197
40	0.025	391	392	388	393
80	0.0125	879	898	904	920
Sample size		174	177	170	165

44) Condition : Kneading temperature = 240 °C
   Speed of screw = 324 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	25	24	25
8	0.125	62	61	59	57
10	0.1	91	87	90	90
16	0.0625	197	200	210	200
20	0.05	300	299	296	287
40	0.025	404	402	347	398
80	0.0125	927	895	862	795
Sample size		201	210	192	200

45) Condition : Kneading temperature = 240 °C
   Speed of screw = 324 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	23	24	25	23
8	0.125	62	61	62	60
10	0.1	91	90	89	92
16	0.0625	199	207	190	187
20	0.05	274	281	290	245
40	0.025	417	421	429	410
80	0.0125	890	918	940	917
Sample size		200	201	197	205

46) Condition : Kneading temperature = 240 °C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 10 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	59	64	59	56
10	0.1	80	85	84	83
16	0.0625	139	153	156	152
20	0.05	161	203	197	187
40	0.025	329	386	374	380
80	0.0125	749	855	829	819
Sample size		200	210	214	217

47) Condition : Kneading temperature = 240°C
Speed of screw = 324 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 20 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	51	55	56
10	0.1	80	86	84	85
16	0.0625	139	133	135	138
20	0.05	181	168	180	177
40	0.025	358	337	350	349
80	0.0125	754	709	751	749
Sample size		210	200	219	217

48) Condition : Kneading temperature = 240°C
Speed of screw = 324 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	23	25
8	0.125	57	61	53	51
10	0.1	79	85	71	71
16	0.0625	142	152	139	140
20	0.05	198	180	157	155
40	0.025	395	377	352	369
80	0.0125	851	887	851	835
Sample size		196	204	200	201

A2.5.2 Quinacridone violet

1) Condition : Kneading temperature = 180 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	24	22	24
8	0.125	62	43	47	51
10	0.1	81	65	61	69
16	0.0625	112	83	93	96
20	0.05	147	105	113	122
40	0.025	247	171	173	197
80	0.0125	438	351	421	405
Sample size		180	170	185	187

2) Condition : Kneading temperature = 180 °C
   Speed of screw = 162 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	22	24	23	24
8	0.125	45	51	43	50
10	0.1	71	65	60	65
16	0.0625	77	99	85	87
20	0.05	90	122	110	117
40	0.025	140	218	159	161
80	0.0125	287	404	335	370
Sample size		155	151	145	150

5) Condition : Kneading temperature = 200 °C
      Speed of screw = 81 rpm
      Feed rate = 51.2 g/min
      Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	59	59	57
10	0.1	78	77	79	80
16	0.0625	122	120	125	124
20	0.05	161	157	159	163
40	0.025	270	269	261	255
80	0.0125	547	540	537	551
Sample size		120	125	122	113

6) Condition : Kneading temperature = 200 °C
      Speed of screw = 81 rpm
      Feed rate = 92.5 g/min
      Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	58	59	60
10	0.1	79	74	75	77
16	0.0625	114	117	109	101
20	0.05	161	157	159	163
40	0.025	260	257	250	249
80	0.0125	539	541	547	529
Sample size		184	179	177	180

3) Condition : Kneading temperature = 180 °C
   Speed of screw = 324 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	23	25	23
8	0.125	51	55	57	54
10	0.1	69	71	78	73
16	0.0625	103	111	113	110
20	0.05	125	123	134	127
40	0.025	220	208	222	217
80	0.0125	476	431	482	463
Sample size		220	221	220	220

4) Condition : Kneading temperature = 180 °C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	23	24	25	24
8	0.125	52	50	49	50
10	0.1	68	72	66	67
16	0.0625	108	103	104	104
20	0.05	135	123	112	123
40	0.025	217	218	193	211
80	0.0125	413	399	413	409
Sample size		175	170	195	178

7) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 30.0 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	61	61	61
10	0.1	90	90	89	91
16	0.0625	155	177	165	156
20	0.05	201	239	210	220
40	0.025	400	435	417	418
80	0.0125	767	853	810	815
Sample size		229	240	235	235

8) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	24	24	23
8	0.125	56	55	56	57
10	0.1	77	74	74	78
16	0.0625	130	135	131	132
20	0.05	159	150	151	155
40	0.025	260	231	187	245
80	0.0125	431	449	337	437
Sample size		115	115	120	110

9) Condition : Kneading temperature = 200 °C
   Speed of screw = 162 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	20	24
8	0.125	61	61	47	62
10	0.1	85	89	71	89
16	0.0625	144	144	116	145
20	0.05	180	191	146	189
40	0.025	335	327	245	307
80	0.0125	667	639	497	605
Sample size		190	171	159	175

10) Condition : Kneading temperature = 200 °C
    Speed of screw = 162 rpm
    Feed rate = 92.5 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	54	56	52	55
10	0.1	82	77	66	80
16	0.0625	118	115	105	117
20	0.05	146	139	109	144
40	0.025	270	262	238	267
80	0.0125	530	528	459	530
Sample size		129	119	111	120

11) Condition : Kneading temperature = 200 °C
   Speed of screw = 243 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	61	61	60	61
10	0.1	86	84	85	84
16	0.0625	141	138	139	140
20	0.05	164	159	147	157
40	0.025	332	312	313	319
80	0.0125	643	575	593	604
Sample size		160	160	160	160

12) Condition : Kneading temperature = 200 °C
   Speed of screw = 243 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	59	60	60
10	0.1	81	82	75	80
16	0.0625	138	149	136	141
20	0.05	159	174	147	160
40	0.025	342	374	317	345
80	0.0125	658	697	702	687
Sample size		195	205	215	205

13) Condition : Kneading temperature = 200 °C
   Speed of screw = 324 rpm
   Feed rate = 30.0 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	61	62	63
10	0.1	87	88	88	89
16	0.0625	155	169	169	170
20	0.05	183	190	191	191
40	0.025	364	380	384	385
80	0.0125	739	778	781	783
Sample size		204	200	196	200

14) Condition : Kneading temperature = 200 °C
   Speed of screw = 324 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	61	60	61
10	0.1	87	87	87	86
16	0.0625	154	146	154	153
20	0.05	172	176	172	173
40	0.025	343	359	321	341
80	0.0125	672	725	622	673
Sample size		180	190	175	180

15) Condition : Kneading temperature = 200 °C
Speed of screw = 324 rpm
Feed rate = 71.9 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	61	59	60
10	0.1	88	94	85	90
16	0.0625	146	149	144	147
20	0.05	199	224	197	210
40	0.025	369	403	369	385
80	0.0125	746	755	744	750
Sample size		221	225	225	225

16) Condition : Kneading temperature = 200 °C
Speed of screw = 324 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	59	57	58
10	0.1	82	79	79	79
16	0.0625	142	137	135	140
20	0.05	172	180	169	164
40	0.025	354	316	337	335
80	0.0125	710	637	677	675
Sample size		190	170	180	180

17) Condition : Kneading temperature = 220 °C
    Speed of screw = 162 rpm
    Feed rate = 51.2 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	23	24	24	24
8	0.125	57	60	61	59
10	0.1	80	85	78	81
16	0.0625	124	156	139	140
20	0.05	156	189	178	174
40	0.025	316	314	321	317
80	0.0125	632	642	648	641
Sample size		150	152	150	150

18) Condition : Kneading temperature = 220 °C
    Speed of screw = 162 rpm
    Feed rate = 92.5 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	55	58	55	56
10	0.1	80	78	70	76
16	0.0625	118	127	116	120
20	0.05	155	151	136	147
40	0.025	311	313	264	296
80	0.0125	621	587	531	580
Sample size		150	155	149	150

19) Condition : Kneading temperature = 220 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	63	63	63
10	0.1	87	88	89	89
16	0.0625	150	169	170	171
20	0.05	183	190	192	191
40	0.025	364	380	384	385
80	0.0125	739	778	781	783
Sample size		214	221	225	220

20) Condition : Kneading temperature = 220 °C
Speed of screw = 324 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	23	24	24	24
8	0.125	57	60	61	59
10	0.1	75	85	78	79
16	0.0625	124	156	139	140
20	0.05	156	189	178	174
40	0.025	316	314	321	317
80	0.0125	632	642	648	641
Sample size		150	152	150	150

21) Condition : Kneading temperature = 240 °C
Speed of screw = 81 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	60	61	60	61
10	0.1	90	89	87	89
16	0.0625	150	149	150	157
20	0.05	180	179	174	173
40	0.025	344	371	314	340
80	0.0125	670	733	720	671
Sample size		197	200	207	195

22) Condition : Kneading temperature = 240 °C
Speed of screw = 81 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	24	24	23
8	0.125	56	55	56	57
10	0.1	79	76	75	81
16	0.0625	134	130	133	139
20	0.05	161	165	157	155
40	0.025	260	231	187	245
80	0.0125	451	470	437	400
Sample size		159	163	153	169

23) Condition : Kneading temperature = 240 °C
   Speed of screw = 162 rpm
   Feed rate = 30.0 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	61	61	61
10	0.1	90	90	89	91
16	0.0625	155	167	165	156
20	0.05	210	231	210	220
40	0.025	421	430	417	418
80	0.0125	770	853	822	820
Sample size		195	205	200	200

24) Condition : Kneading temperature = 240 °C
   Speed of screw = 162 rpm
   Feed rate = 51.2 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	59	62	63	61
10	0.1	89	88	91	89
16	0.0625	146	155	162	154
20	0.05	161	183	199	181
40	0.025	313	375	387	358
80	0.0125	638	650	756	681
Sample size		166	199	218	195

25) Condition : Kneading temperature = 240 °C
Speed of screw = 162 rpm
Feed rate = 71.9 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	62	62	61
10	0.1	91	86	91	91
16	0.0625	164	152	160	150
20	0.05	210	202	217	211
40	0.025	410	395	450	415
80	0.0125	810	809	830	815
Sample size		241	270	235	250

26) Condition : Kneading temperature = 240 °C
Speed of screw = 162 rpm
Feed rate = 92.5 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	57	60	59	61
10	0.1	75	74	79	75
16	0.0625	107	120	118	109
20	0.05	159	155	157	163
40	0.025	272	275	274	277
80	0.0125	550	552	551	553
Sample size		140	145	130	149

27) Condition : Kneading temperature = 240 °C
    Speed of screw = 243 rpm
    Feed rate = 51.2 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	59	60	63
10	0.1	93	86	90	95
16	0.0625	176	154	165	180
20	0.05	204	176	190	205
40	0.025	407	379	393	410
80	0.0125	815	735	775	819
Sample size		215	200	210	215

28) Condition : Kneading temperature = 240 °C
    Speed of screw = 243 rpm
    Feed rate = 92.5 g/min
    Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	61	62	61
10	0.1	82	81	81	82
16	0.0625	144	139	141	143
20	0.05	172	152	169	164
40	0.025	354	316	337	335
80	0.0125	710	637	677	675
Sample size		190	170	180	180

29) Condition : Kneading temperature = 240 °C
Speed of screw = 324 rpm
Feed rate = 30.0 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	24	24	24	23
8	0.125	64	64	63	63
10	0.1	97	96	94	95
16	0.0625	169	191	170	165
20	0.05	205	236	210	200
40	0.025	446	454	450	443
80	0.0125	818	849	820	815
Sample size		195	199	197	184

30) Condition : Kneading temperature = 240 °C
Speed of screw = 324 rpm
Feed rate = 51.2 g/min
Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	64	62	63	62
10	0.1	93	92	92	92
16	0.0625	183	181	182	181
20	0.05	255	260	255	258
40	0.025	472	466	470	471
80	0.0125	847	857	850	848
Sample size		225	237	223	239

31) Condition : Kneading temperature = 240 °C
   Speed of screw = 324 rpm
   Feed rate = 71.9 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	64	63	63	63
10	0.1	93	96	94	92
16	0.0625	169	191	170	165
20	0.05	205	236	210	200
40	0.025	446	454	450	443
80	0.0125	818	849	820	815
Sample size		237	243	245	240

32) Condition : Kneading temperature = 240 °C
   Speed of screw = 324 rpm
   Feed rate = 92.5 g/min
   Pre-mixed time = 30 min

n	r	N(r)			
		1	2	3	4
2	0.5	4	4	4	4
4	0.25	16	16	16	16
5	0.2	25	25	25	25
8	0.125	62	60	61	60
10	0.1	89	84	87	85
16	0.0625	156	146	151	149
20	0.05	200	177	189	179
40	0.025	349	318	334	320
80	0.0125	623	579	601	594
Sample size		190	173	180	180

A2.6 Effect of the key kneading conditions on the tensile properties and normalized fractal dimension in the case of carbon black pigment

T (°C)	R (rpm)	Strain @ break (%)	Work done (N-mm)	0.2% offset stress (N/mm²)	E (N/mm²)	D*
200	162	170.4	3105	20.8	214.5	0.931
		174.9	3258	22.7	198.6	0.932
		175.1	3040	20.8	187.4	0.934
		170.6	3019	21.9	317.2	0.928
		160.6	2780	20.5	205.4	0.930
		173.4	2935	21.8	216.1	0.929
		150.3	2932	21.8	222.5	0.929
		175.1	2751	19.9	225.1	0.930
	Avg.	**168.8**	**2978**	**21.3**	**223.4**	**0.931**
	243	100.4	1757	21.4	223.0	0.968
		132.8	2520	21.2	186.6	0.962
		138.3	2447	27.6	217.1	0.952
		143.9	2045	24.1	212.6	0.970
	Avg.	**128.9**	**2192**	**23.6**	**209.8**	**0.963**
	324	94.8	2074	22.4	243.9	0.981
		98.6	2046	21.5	203.3	0.981
		96.3	2017	21.1	195.1	0.979
		106.0	2023	21.0	262.5	0.969
		100.1	2049	21.2	212.3	0.969
		11.6	2081	29.2	261.2	0.977
		112.9	2079	30.1	260.2	0.979
		113.8	2025	25.8	232.3	0.971
	Avg.	**104.3**	**2117**	**24.0**	**233.9**	**0.976**
220	162	53.0	1114	23.2	249.7	0.942
		65.1	1279	23.9	195.8	0.950
		96.1	1817	26.2	220.0	0.933
		127.1	2280	23.5	233.6	0.934
	Avg.	**85.3**	**1663**	**24.2**	**224.8**	**0.940**
	324	60.0	826	24.8	239.5	0.993
		55.4	1008	24.9	226.6	0.989
		107.8	1298	30.1	247.4	0.978
		96.7	1630	27.9	347.9	0.981
	Avg.	**80.0**	**1191**	**26.9**	**265.4**	**0.985**

A2.6 Effect of the key kneading conditions on the tensile properties and normalized fractal dimension in the case of carbon black pigment (continued)

T (°C)	R (rpm)	Strain @ break (%)	Work done (N-mm)	0.2% offset stress (N/mm^2)	E (N/mm^2)	D*
240	162	69.5	1464	31.7	242.3	0.955
		63.2	1350	27.6	274.8	0.953
		63.8	1302	30.1	252.1	0.957
		69.7	1030	32.8	271.4	0.953
		65.1	1219	29.6	252.4	0.949
		70.1	1089	27.8	288.2	0.952
		45.1	932	28.3	226.1	0.953
		56.7	929	26.7	245.4	0.957
	Avg.	**62.9**	**1164**	**29.3**	**256.6**	**0.954**
	243	58.8	955	25.1	234.6	0.979
		55.7	1018	30.5	262.5	0.976
		53.3	883	28.3	252.2	0.963
		38.1	768	30.3	259.8	0.974
	Avg.	**51.5**	**906**	**28.6**	**252.3**	**0.973**
	324	55.9	1004	27.4	253.9	0.996
		50.8	919	26.1	255.1	0.994
		46.8	847	31.7	320.9	0.997
		53.1	1054	26.7	235.1	0.989
		44.8	1005	27.4	342.0	0.997
		51.0	983	30.9	279.5	0.982
		40.2	731	28.3	233.6	0.982
		39.0	647	29.3	361.9	0.986
	Avg.	**47.7**	**899**	**28.5**	**285.3**	**0.991**

A2.7 Effect of the key kneading conditions on the tensile properties and normalized fractal dimension in the case of quinacridone violet pigment

T (°C)	R (rpm)	Strain @ break (%)	Work done (N-mm)	0.2% offset stress (N/mm²)	E (N/mm²)	D*
	162	155.4	2680	21.0	119.8	0.829
		147.8	2729	21.1	164.9	0.812
180	Avg.	151.6	2705	21.0	142.4	0.821
	324	136.7	1626	22.2	156.4	0.855
		103.1	2182	23.3	217.3	0.846
	Avg.	119.9	1904	22.7	186.9	0.851
	81	121.7	2379	19.7	149.4	0.915
		125.9	2579	24.2	150.5	0.873
	Avg.	123.8	2479	21.9	150.0	0.894
		100.9	2132	23.7	158.5	0.955
		113.5	2240	21.8	159.7	0.931
	162	115.3	2060	23.6	214.6	0.923
		124.6	2363	24.2	222.5	0.893
200	Avg.	113.5	2199	23.3	188.8	0.926
	243	89.7	1789	25.2	214.7	0.935
		116.1	2323	25.0	235.3	0.919
	Avg.	102.9	2056	25.1	225.0	0.927
		86.2	1272	23.9	126.4	0.960
		87.2	1582	27.4	220.2	0.948
	324	97.0	1781	24.0	216.9	0.934
		100.4	2208	25.3	245.6	0.921
	Avg.	92.7	1711	25.2	202.3	0.941
	162	52.2	1039	23.9	195.2	0.936
		69.2	1607	25.1	239.8	0.896
220	Avg.	60.7	1323	24.5	217.5	0.916
	324	68.2	1389	31.0	248.6	0.957
		48.1	844	27.7	251.6	0.933
	Avg.	58.2	1116	29.3	250.1	0.945
	81	37.8	712	24.2	161.9	0.945
		39.1	698	24.0	159.7	0.911
	Avg.	38.5	705	24.1	160.8	0.928
		29.2	466	25.4	155.3	0.959
	162	35.5	466	26.7	208.7	0.949
		31.5	529	27.4	230.8	0.948
		35.4	671	28.1	257.7	0.917
240	Avg.	32.9	533	26.9	213.1	0.943
	243	33.7	518	27.5	210.2	0.949
		36.6	685	29.3	259.9	0.930
	Avg.	35.2	601	28.4	235.1	0.940
		39.0	506	32.2	188.6	0.982
	324	36.8	649	31.9	252.8	0.979
		38.7	893	30.6	251.3	0.973
		38.1	735	30.8	283.0	0.946
	Avg.	38.2	696	31.4	243.9	0.970

A2.8 Estimated number of pigment particles in a SEM microphotograph sample

1) In the case of carbon black

From the experimental procedure, HDPE and carbon black are premixed in raeio 25:1 by wt.

Basis: Weight of HDPE	=	25	g
Weight of carbon black	=	1	g
Density of HDPE	=	0.968	g/cm^3
Density of carbon black	=	2.25	g/cm^3
Median particle size of carbon black =	0.02		μm

Volume of HDPE $= 25 / 0.968 = 25.83$ cm^3

Volume of carbon black $= 1 / 2.25 = 0.44$ cm^3

Thus, total volume $= 25.83 + 0.44 = 6.27$ cm^3

Volume of each carbon black particle $= 4/3 \, \pi (0.02/2 \, \mu m)^3$

$$= 4.19 \times 10^{-6} \quad \mu m^3$$

Total particles of carbon black $= 0.44 \times 10^{12} / 4.19 \times 10^{-6}$

$$= 1.05 \times 10^{19} \quad \text{particles}$$

Number of carbon black per unit volume $= 1.05 \times 10^{19} / (26.27 \times 10^{12})$

$$= 3.99 \times 10^5 \quad \text{particle}/\mu m^3$$

Total area of a SEM photograph $= 40.96 \quad \mu m^2$

Assume 1 μm depth of field depth

$\therefore$ Number of particles in a SEM photograph $= 3.99 \times 10^5 \times 40.96 \times 1.0$

$$= 1.63 \times 10^7 \quad \text{particles}$$

2) In the case of quinacridone violet

A ratio between HDPE and quinacridene violet is 25:1 by weight

Basis :
Weight of HDPE	=	25	g	
Weight of quinacridone violet	=	1	g	
Density of HDPE	=	0.968	g/cm^3	
Density of quinacridone violet	=	1.5	g/cm^3	
Median particle size of quinacridone violet	=	0.12	μm	

volume of HDPE = 25 / 0.968 = 25.83 cm^3

volume of quinacridone violet = 1 / 1.5 = 0.67 cm^3

Thus, total volume = 25.83+0.67 = 26.5 cm^3

volume of each pigment particle = $4 / 3 \, \pi (0.12 / 2 \, \mu m)^3$ μm^3

= 9.05 x 10^{-4} μm^3

Total particles of pigment = 0.67 x 10^{12} / 9.05 x 10^{-4} particles

= 7.40 x 10^{14} particles

Then, number of pigments per unit volume = 7.40 x 10^{14} / (26.5 x 10^{12})

= 27.92 particles/μm^3

Total area of a SEM photograph = 113.78 μm^2

Assume 1 μm depth of field depth

Thus, number of particles in one SEM photograph = 113.78 x 1.0 x 27.92

= 3176.7 particles

$\approx$ 3177 particles

A3. Simulation program

A3.1 Listing of simulation program (Qbasic language)

```
'      ********************************************************************
'      ***  Q       =  Amount of particle                          ***
'      ***  MS      =  Maximum of division                         ***
'      ***  S       =  No. of division                            ***
'      ***  Z(X,Y)  =  particle                                    ***
'      ***  ST      =  Counting step                               ***
'      ***  P ( )   =  Amount of particle in a segment             ***
'      ***  SF ( )  =  Area ratio of particle                      ***
'      ***  MSF     =  Mean ratio of patrcle area                  ***
'      ***  SUM     =  Summation of SF                             ***
'      ***  SSUM    =  Summation of ( MSF - SF )²                  ***
'      ***  STD     =  Standard deviation of  SF                   ***
'      ***  DS      =  Coefficient of variance = STD / MSF         ***
'      ***  TP      =  Total of particle                          ***
'      ***  B       =  Total of empty segments  ( No  particle )  ***
'      ***  TB      =  Amount of segments that have particle       ***
'      ***  A       =  Total of segments                          ***
'      ********************************************************************

DECLARE SUB SUBUNIFORM ( )
DECLARE SUB SUB2 ( )
DECLARE SUB SUB1 ( )
COMMON SHARED IY, IA, IT, IT AS LONG
COMMON SHARED PAI, RANR, TI, TR, XO, XT, YY AS DOUBLE
COMMON SHARED Q, MS, N, S, Z ( ), ST, P ( ), Sf, MSF, SUM, SSUM, STD, Ds, A,
                B, TB, A  AS DOUBLE
DIM  Z ( 100, 100 ), P ( 100, 100), Sf (100, 100)
CLS
INPUT "TI = ", TI
PRINT "TI = "; TI
IT  =  TI * 101#
100    IF  (IT - 24350542) < 0  THEN GOTO 200 ELSE 150
```

```
150     IT = IT/10
        GOTO 100
200     IY = 42758321 + IT
        IA = INT(IY/2)
        IY = IA * 2 + 1
        INPUT "Sample population size = ", Q
        INPUT "Mean particle size (micron) = ", MP
        PAI = 4# * ATN(1#)
        AP = PAI *(MP/2)^2
        INPUT "The observed area = "; OA
        INPUT "Maximum of division = ", MS
        PRINT
        PRINT "—————————————————————————————————"
        PRINT "Type of random"
        PRINT " 1.  Uniform random number generator  "
        PRINT " 2.  Normal random number generator  "
        PRINT "—————————————————————————————————"
        PRINT
        Z ( X, Y ) = 0
        INPUT "Type of random ( 1, 2 ) = "; N
        PRINT
        PRINT "— If you want to stop, input number of division = 0 —"
        SELECT CASE N
            CASE IS = 1
                CALL SUB1
            CASE IS = 2
                CALL SUB2
        END SELECT
        PRINT
        DO
            A = 0: B = 0: TB = 0: TP = 0: SUM = 0: SSUM = 0: SF ( I, J ) = 0
            INPUT "Number of division ( S x S ) = "; S
            IF S = 0 THEN END
            ST = MS / S
            FOR I = 1 TO S
                FOR J = 1 TO S
```

```
                    P(I,J) = 0
                    FOR  I2 = 1 TO  ST: I3 = ( I - 1 ) * ST + I2
                        FOR  J2 = 1 TO  ST: J3 = ( J - 1 ) * ST + J2
                            P ( I , J ) = P ( I , J ) + Z ( I3 , J3 )
                        NEXT J2
                    NEXT I2
                    A = A + 1
                    IF  P ( I , J ) = 0 THEN B = B + 1 ELSE TP = TP + P
                    SF ( I , J ) = P ( I , J ) * AP / ( OA / S ^ 2 )
                    IF SF ( I , J ) > 1 THEN SF ( I , J ) = 1
                    SUM = SUM + SF ( I , J )
                NEXT J
            NEXT I
        MSF = SUM / A
        FOR I = 1 TO S
            FOR J = 1 TO S
                SSUM = SSUM + ( MSF - SF ( I , J ) ) ^ 2
            NEXT J
        NEXT I
        STD = SSUM / ( S ^ 2 - 1 )
        DS = STD / MSF
        TB = S ^ 2 - B
        PRINT "————————————————————————————————"
        PRINT TAB (1) ; "Empty segments = ";  B;  TAB (25);  "Total of segments = ";  A;
                TAB(53);  "Total of particles = ";  TP
        PRINT
        PRINT "Total of segments that have particle  = [";  TB;  "]"
        PRINT "————————————————————————————————"
        PRINT "EVALUATION OF TERASHITA et.al. (1993)
        PRINT
        PRINT TAB (1) "MEAN SF  = ";  MSF;  TAB (27);  " STANDARD DEVE. = ";  STD ;
        TAB (57);  "DS  = [";  DS;  "]"
        PRINT "————————————————————————————————"
        PRINT
LOOP
END
```

```
SUB  SUB1
    FOR I = 1 TO Q
        CALL SUBUNIFORM
        X = INT ( RANR * MS + 1 )
        CALL SUBUNIFORM
        Y = INT ( RANR * MS + 1 )
        Z ( X, Y ) = Z ( X, Y ) + 1
    NEXT I
END  SUB
SUB  SUB2
    FOR I = 1 TO Q
        CALL SUBUNIFORM
        XO = SQR ( -2# * LOG ( RANR ) )
        CALL SUBUNIFORM
        XR = 6.2831853072# * RANR
        XT = XO * SIN ( XR )
        X = INT ( XT / 3 * MS /2 + MS / 2 + 1 )
        IF X > 80 THEN X = 80
        IF X < 1 THEN X = 1
        CALL SUBUNIFORM
        YO = SQR ( -2# * LOG ( RANR ) )
        CALL SUBUNIFORM
        YR = 6.2831853072# * RANR
        YT = YO * SIN ( YR )
        Y = INT ( YT / 3 * MS /2 + MS / 2 + 1 )
        IF Y > 80 THEN Y = 80
        IF Y < 1 THEN Y = 1
        Z ( X, Y ) = Z ( X, Y ) + 1
    NEXT I
END  SUB
SUB SUBUNIFORM
    YY = 3125# * IY
    IY = INT(YY/67108864# + 1# * 10 ^ (-8))
    IY = INT(YY - IY * 67108864# + 0.05)
    RANR = IY / 67108864#
END  SUB
```

Vita

Miss Arunya Thongchiew was born in Prachuabkirikhun, Thailand, on April 8, 1971. She received her Bachelor Degree of Science from the Department of Chemical Technology, Faculty of Science, Chulalongkorn University in 1993.