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APPENDICES

Appendix A Absorbance of pure methyl violet (MV) under UV irradiation for 5 hours. The concentration of MV is 5 ppm.

Table A1 The result from measurement the absorbance of pure MV under UV irradiation for 5 hours

Time (hrs)	0	1	2	3	4	5
Absorbance	0.608623	0.555232	0.536014	0.497331	0.475675	0.46782

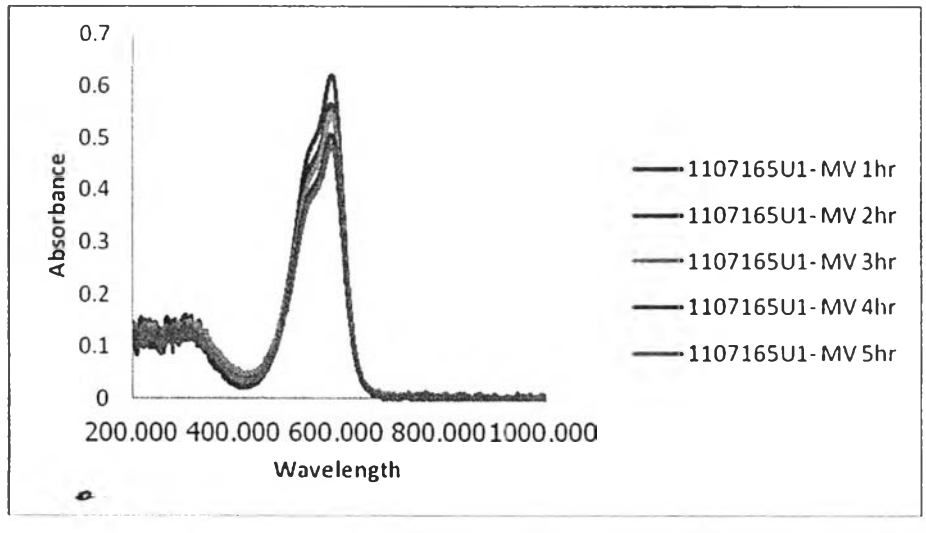

Figure A1 Show the absorbance of MV under UV irradiation for 5 hours

APPENDIX B Find the best condition to synthesize Cerium oxide (CeO_2) followed by the photo-catalytic activity with MV under UV irradiation for 5 hours. The concentration of MV is 5 ppm.

There are various conditions to synthesize which are synthesize by stirring or sonication, quick added or drop wise of Na_2CO_3 and Heat at 60 C or Room temperature. These ways to synthesize CeO_2 will be shown in this appendix.

*P.S. H = heat at 60 C, R = room temperature, Q = quick mixing, Slo = slow mixing, sonic. = sonication, S = stirring, 8 = pH 8.0

Table B1 The absorbance of MV in the presence of CeO_2 which synthesized by quick added and drop wise of Na_2CO_3 at wavelength 582.557 cm^{-1}

Condition	0	1	2	3	4	5
R,8,S,Slo	0.608623	0.509927	0.492066	0.447499	0.382762	0.361438
R,8,S,Q	0.608623	0.493401	0.19055	0.163753	0.028516	0.003107

Table B2 The absorbance of MV in the presence of CeO_2 which synthesized by sonicated and stirred condition at wavelength 582.557 cm^{-1}

Condition	0	1	2	3	4	5
R,8,sonic,Q	0.608623	0.560393	0.398563	0.211754	0.142595	0.026056
R,8,S,Q	0.608623	0.493401	0.19055	0.163753	0.028516	0.003107

Table B3 The absorbance of MV in the presence of CeO_2 which synthesized at 60 C and room temperature at wavelength 582.557 cm^{-1}

Condition	0	1	2	3	4	5
H,8,S,Q	0.608623	0.361998	0.267529	0.230512	0.161364	0.068694
R,8,S,Q	0.608623	0.493401	0.19055	0.163753	0.028516	0.003107

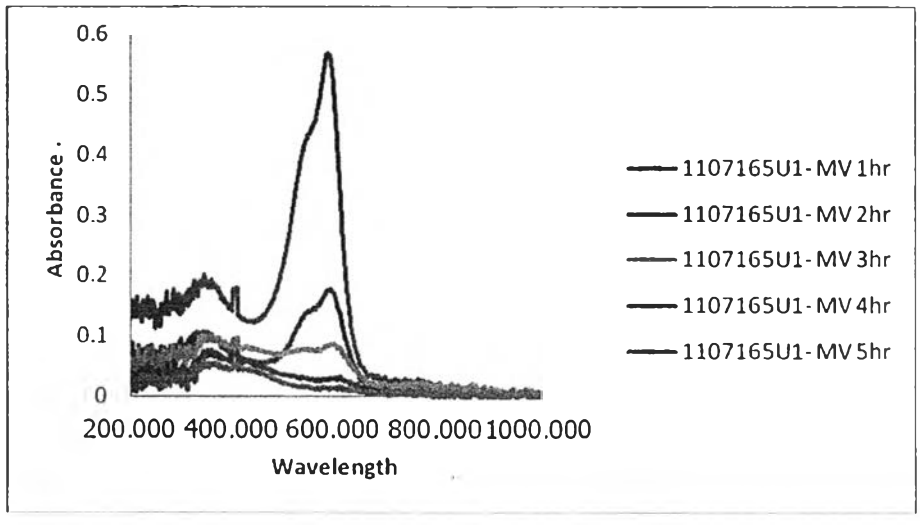

Figure B1 Show the absorbance of CeO_2 synthesized by the best condition which is synthesize at room temperature, pH 8.0 and quick added Na_2CO_3 under stirred condition

Appendix C Compare the photo-catalytic activity between $Ce(OH)CO_3$, CeO_2 and also, compare to pure MV under UV irradiation for 5 hours

This part of experiment was used to confirm that CeO_2 is the photo-catalyst not $Ce(OH)CO_3$ or degradation of MV by itself.

Table C1 Show the absorbance of MV in the presence of $Ce(OH)CO_3$, CeO_2 and also pure MV under UV irradiation for 5 hours at wavelength 582.557 cm^{-1}

Substance	0	1	2	3	4	5
$Ce(OH)CO_3$	0.608623	0.555232	0.495869	0.481388	0.404118	0.397563
CeO_2	0.608623	0.493401	0.19055	0.163753	0.028516	0.003107
Pure MV	0.608623	0.555232	0.536014	0.497331	0.475675	0.46782

Appendix D Study on the charges at the surface of $Ce(OH)CO_3$ and CeO_2 at any pH

The charges at the surface of $Ce(OH)CO_3$ and CeO_2 was studied by using layer-by-layer technique. The glass slide will be prepared to be negative charge (6 layers) and positive charges (5 layers) by layer-by-layer technique. The primer will be dipped in the $Ce(OH)CO_3$ and CeO_2 which dispersed in the distilled water at pH 3-10.

Table D1 Show the absorbance of primer dipped into the $Ce(OH)CO_3$ at pH 3-10

pH	5	6	7	8	9	10
6 layers	0.056139	0.052126	0.060263	0.068056	0.075076	0.101478
5 layers	0.01815	0.031706	0.041672	0.044476	0.043935	0.036738

Table D2 Show the absorbance of primer dipped into the CeO_2 at pH 3-10

pH	Number of primers			
	5 layers	6 layers	SD 5 layers	SD 6 layers
3	0.110233	0.312076	0.040588	0.01968
4	0.147659	0.51617	0.051851	0.026242
5	0.304587	0.499408	0.126099	0.07452
6	0.293243	0.09459	0.0475	0.033157
7	0.128347	0.005467	0.034793	0.001278
8	0.139439	0.001165	0.011033	0.000578
9	0.120916	0.009429	0.004102	0.001111
10	0.128656	0.004858	0.000911	0.001045

Appendix E Show the effect of Ag nanoparticles on CeO_2

The CeO_2 nanoparticles were synthesized at the surface of Ag nanoparticles. Ag nanoparticles were synthesized by chemical reduction of $AgNO_3$ using COPSS and $NaBH_4$ as capping agent and reduced agent, respectively. The photo-catalytic activity of CeO_2 with Ag nanoparticles will be shown in appendix E.

Table E1 Show the absorbance of MV in the presence of CeO_2 with Ag nanoparticles which synthesized by various concentrations of COPSS

Time (minutes)	Concentration of COPSS				Pure CeO_2
	0.001 mM	0.005 mM	0.01 mM	0.05 mM	
0	1.154795	1.154795	1.154795	1.154795	1.154795
3	0.724211	0.693124	0.753318	0.705132	1.109679
5	0.699163	0.655183	0.741259	0.674934	1.084518
10	0.669382	0.650617	0.597784	0.624341	1.014098
20	0.668863	0.621737	0.516211	0.600853	0.875797
30	0.66825	0.587677	0.489824	0.559313	0.838016
60	0.631036	0.569543	0.458964	0.546586	0.832655
120	0.595987	0.5557	0.442541	0.489042	0.82099

Table E2 Show the absorbance of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO_2 with Ag nanoparticles synthesized by various concentrations of COPSS

Time (minutes)	Concentration of COPSS				Pure CeO_2
	0.001 mM	0.005 mM	0.01 mM	0.05 mM	
0	1	1	1	1	1
3	0.627134	0.600214	0.65234	0.610612	0.960932
5	0.605443	0.567359	0.641897	0.584463	0.939144
10	0.579654	0.563405	0.517654	0.540651	0.878163
20	0.579205	0.538396	0.447015	0.520312	0.7584
30	0.578674	0.508902	0.424166	0.484339	0.725684
60	0.546448	0.493198	0.397442	0.473318	0.721042
120	0.516097	0.481211	0.383221	0.423488	0.71094

Table E3 Show the absorbance of MV in the presence of CeO_2 with Ag nanoparticles which synthesized by various concentrations of $AgNO_3$

Time (minutes)	CeO_2 with various concentration of $AgNO_3$				TiO_2	CeO_2
	5 mM	10 mM	1 mM	2 mM		
0	1.154795	1.154795	1.154795	1.154795	1.154795	1.154795
3	0.510163	0.622417	0.428171	0.524106	1.154561	1.109679
5	0.50939	0.576153	0.420825	0.501172	1.086929	1.084518
10	0.49048	0.562532	0.420447	0.464017	1.07269	1.014098
20	0.481897	0.545641	0.412081	0.452937	1.050339	0.875797
30	0.466113	0.507455	0.409408	0.452911	0.675412	0.838016
60	0.454636	0.490018	0.373557	0.433234	0.454029	0.832655
120	0.408141	0.484912	0.367135	0.410589	0.43888	0.82099

Table E4 Show the absorbance of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO_2 with Ag nanoparticles synthesized by various concentrations of $AgNO_3$

Time (minutes)	CeO_2 with various concentration of $AgNO_3$				Pure CeO_2
	5 mM	10 mM	1 mM	2 mM	
0	1	1	1	1	1
3	0.441778	0.538985	0.370777	0.453852	0.960932
5	0.441109	0.498922	0.364415	0.433992	0.939144
10	0.424734	0.487127	0.364088	0.401817	0.878163
20	0.417301	0.472501	0.356843	0.392223	0.7584
30	0.403632	0.439433	0.354528	0.392201	0.725684
60	0.393694	0.424334	0.323483	0.375161	0.721042
120	0.353431	0.419912	0.317922	0.355551	0.71094

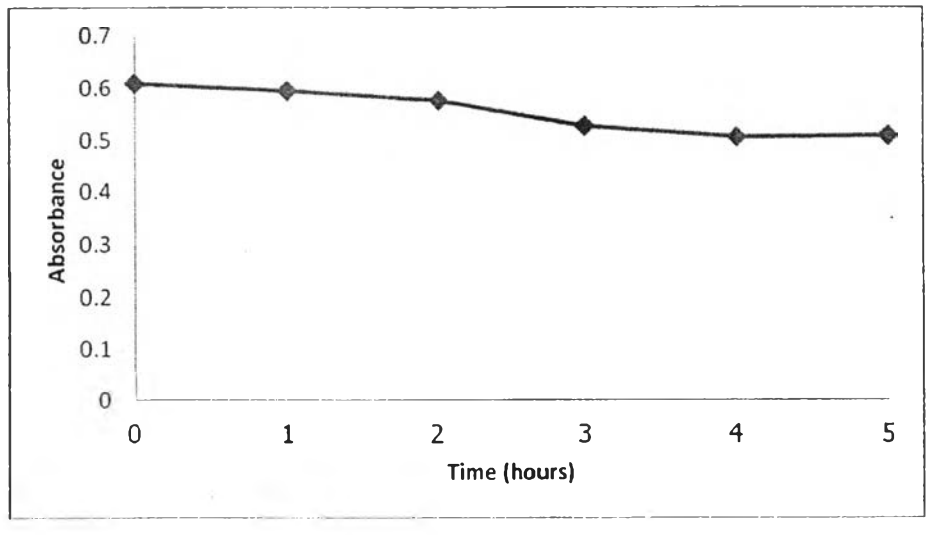

Figure E1 Show the degradation of MV in the presence of pure Ag nanoparticles

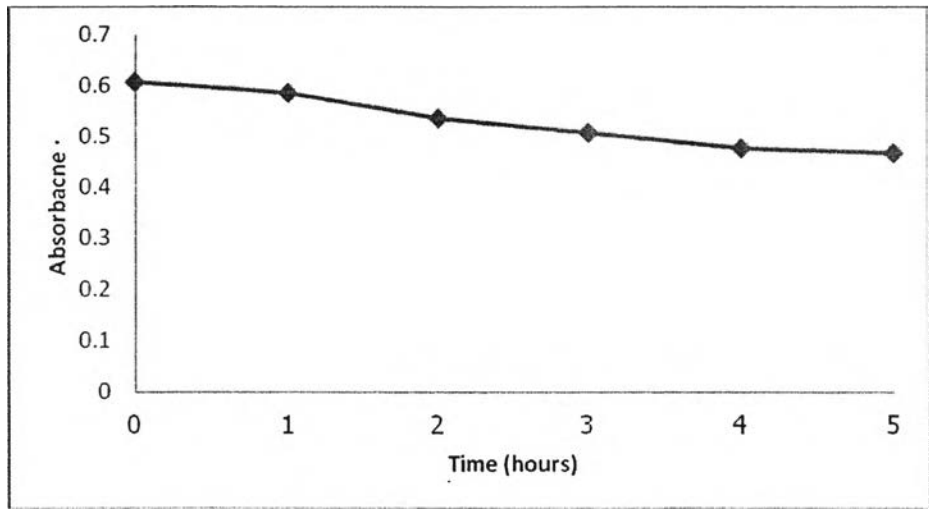

Figure E2 Show the degradation of MV in the presence of $AgNO_3$

Appendix F Show the effect of polyelectrolytes on the synthesis of CeO_2

The polyelectrolytes which are PAA, PDADMAC, PSS and COPSS can improve the photo-catalytic activity of CeO_2 due to they can control the size of CeO_2. The best condition and type of polyelectrolytes will be chosen followed by the photo-catalytic activity. The concentration of MV in this part is 10 ppm.

Table F1 Show the absorbance of MV in the presence of CeO_2 synthesize with PAA at any concentration

Time (hours)	Concentration				
	5 mM	10 mM	20 mM	30 mM	50 mM
0	0.611512	0.611512	0.611512	0.611512	0.611512
1	0.164595	0.151518	0.113112	0.156708	0.192873
2	0.125107	0.108419	0.105815	0.110471	0.168506
3	0.103101	0.105347	0.105883	0.108442	0.124876
4	0.091222	0.080199	0.069109	0.07722	0.101974
5	0.081137	0.079763	0.025215	0.054767	0.090455

Table F2 Show the absorbance of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO_2 synthesize with PAA at any concentration

Time (hours)	Concentration				
	5 mM	10 mM	20 mM	30 mM	50 mM
0	1	1	1	1	1
1	0.26916	0.247776	0.184971	0.256263	0.315404
2	0.204587	0.177296	0.173038	0.180652	0.275556
3	0.1686	0.172272	0.17315	0.177334	0.204208
4	0.149174	0.131149	0.113013	0.126277	0.166757
5	0.132683	0.130436	0.041235	0.089559	0.14792

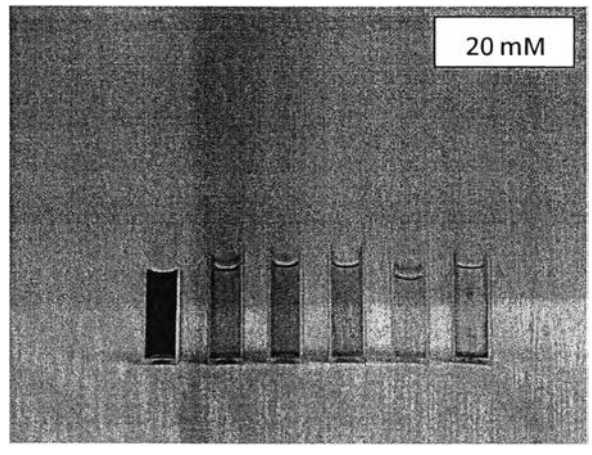

Figure F1 Show the degradation of MV in the presence of CeO_2 synthesized with PAA at any concentration and also showed the picture of best condition at 20 mM PAA

Table F3 Show the absorbance of MV in the presence of CeO_2 synthesize with PDADMAC at any concentration

Time (hours)	Concentration				
	5 mM	10 mM	20 mM	30 mM	50 mM
0	0.611512	0.611512	0.611512	0.611512	0.611512
1	0.155655	0.141036	0.144063	0.12306	0.157668
2	0.150666	0.122201	0.131143	0.108096	0.155225
3	0.146921	0.120589	0.112277	0.101259	0.144047
4	0.143568	0.119901	0.100094	0.104383	0.139748
5	0.110469	0.104129	0.099407	0.101881	0.137399

Table F4 Show the absorbance of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO2 synthesize with PDADMAC at any concentration

Time (hours)	Concentration				
	5 mM	10 mM	20 mM	30 mM	50 mM
0	1	1	1	1	1
1	0.254542	0.230636	0.235584	0.201239	0.257833
2	0.246383	0.199835	0.214458	0.176769	0.253838
3	0.240258	0.197199	0.183606	0.165588	0.235559
4	0.234775	0.196073	0.163684	0.170697	0.228529
5	0.180649	0.170281	0.162559	0.166604	0.224687

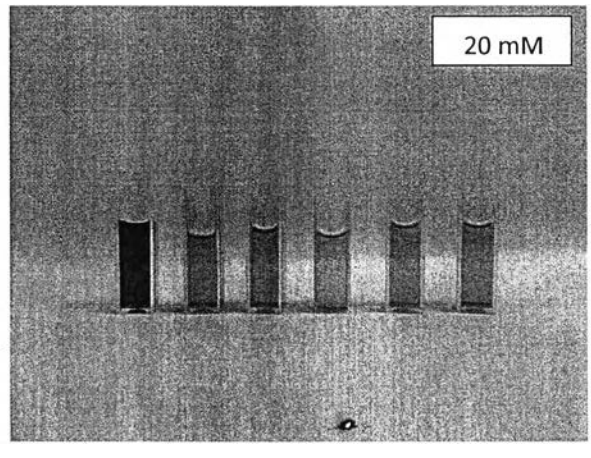

Figure F2 Show the degradation of MV in the presence of CeO_2 synthesized with PDADMAC at any concentration and also showed the picture of best condition at 20 mM PDADMAC

Table F5 Show the absorbance of MV in the presence of CeO_2 synthesize with COPSS at any concentration

Time (hours)	Concentration				
	5 mM	10 mM	20 mM	30 mM	50 mM
0	0.611512	0.611512	0.611512	0.611512	0.611512
1	0.147197	0.116606	0.118694	0.150685	0.185996
2	0.112474	0.124634	0.103249	0.123467	0.139242
3	0.126564	0.110517	0.09149	0.113483	0.124585
4	0.114291	0.098832	0.086583	0.103779	0.130842
5	0.110214	0.083684	0.057837	0.103492	0.12865

Table F6 Show the absorbance of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO_2 synthesize with COPSS at any concentration

Time (hours)	Concentration				
	5 mM	10 mM	20 mM	30 mM	50 mM
0	1	1	1	1	1
1	0.24071	0.190685	0.194099	0.246414	0.304158
2	0.183928	0.203814	0.168843	0.201905	0.227701
3	0.206969	0.180727	0.149613	0.185578	0.203733
4	0.186898	0.16162	0.141589	0.169709	0.213964
5	0.180231	0.136848	0.09458	0.169239	0.210381

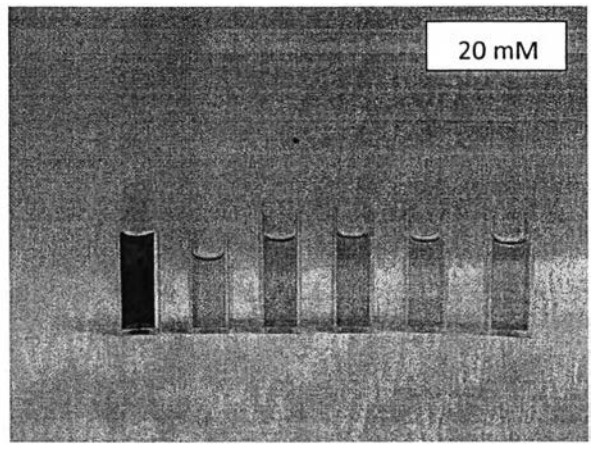

Figure F3 Show the degradation of MV in the presence of CeO_2 synthesized with COPSS at any concentration and also showed the picture of best condition at 20 mM COPSS

Table F7 Compare the photo-catalytic activity of CeO_2 synthesized by various types of 20 mM polyelectrolyte and also Ag nanoparticles

Time (minutes)	Types of polymer and metal					
	PDAD	PAA	COPSS	Pure CeO_2	PSS	Ce/Ag
0	1.154795	1.154795	1.154795	1.154795	1.154795	1.154795
3	1.010767	0.632478	0.774946	1.109679	0.842131	0.705132
5	0.918841	0.624028	0.70923	1.084518	0.805193	0.674934
10	0.874847	0.592389	0.709209	1.014098	0.763955	0.624341
20	0.87238	0.507306	0.689141	0.875797	0.731541	0.500853
30	0.862437	0.505201	0.62144	0.838016	0.717983	0.459313
60	0.85612	0.501391	0.589969	0.832655	0.631212	0.446586
120	0.805823	0.498545	0.552477	0.82099	0.628081	0.389042

Table F8 Show the absorbance of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO_2 synthesize with various types of polyelectrolytes and also Ag nanoparticles

Time (minutes)	Types of polymer and metal					
	PDAD	PAA	COPSS	Pure CeO_2	PSS	Ce/Ag
0	1	1	1	1	1	1
3	0.875278	0.547697	0.671068	0.960932	0.729247	0.610612
5	0.795675	0.54038	0.614161	0.939144	0.697261	0.584463
10	0.757578	0.512982	0.614143	0.878163	0.66155	0.540651
20	0.755441	0.439304	0.596765	0.7584	0.633481	0.433716
30	0.746831	0.437481	0.538139	0.725684	0.621741	0.397744
60	0.741361	0.434182	0.510887	0.721042	0.546601	0.386723
120	0.697807	0.431717	0.47842	0.71094	0.54389	0.336893

Table F9 Show the absorbance at various concentration of MV in the presence of CeO_2 synthesized by using 20 mM PAA as capping agent

Time (minutes)	Concentration of MV		
	0.05g/L	0.025g/L	0.01 g/L
0	4	1.88666	1.154795
3	1.378196	0.66249	0.632478
5	0.92707	0.641136	0.624028
10	0.922331	0.631963	0.592389
20	0.905141	0.61867	0.507306
30	0.846616	0.602896	0.505201
60	0.830014	0.602647	0.501391
120	0.697494	0.59184	0.498545

Table F10 Show the absorbance at various concentrations of MV after exposure to UV compare to the absorbance of MV before exposure to UV in the presence of CeO_2 synthesized by 20 mM PAA

Time (minutes)	Concentration of MV		
	0.05g/L	0.025g/L	0.01 g/L
0	1	1	1
3	0.344549	0.351145	0.547697
5	0.231767	0.339826	0.54038
10	0.230583	0.334964	0.512982
20	0.226285	0.327918	0.439304
30	0.211654	0.319558	0.437481
60	0.207503	0.319425	0.434182
120	0.174374	0.313697	0.431717

Appendix G Show the XRD graph of the photo-catalyst to confirm that the catalyst is CeO_2 or CeO_2 with Ag nanoparticles

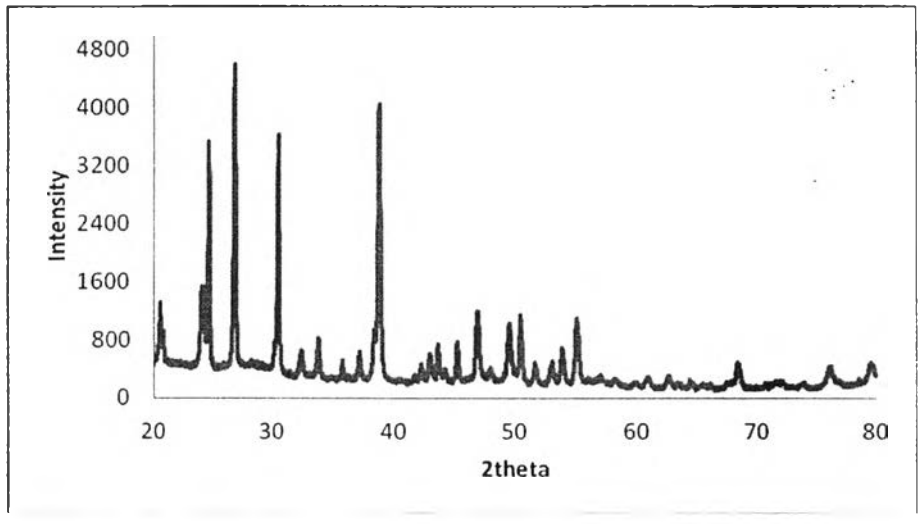

Figure G1 Show the XRD graph of $Ce(OH)CO_3$ before calcination

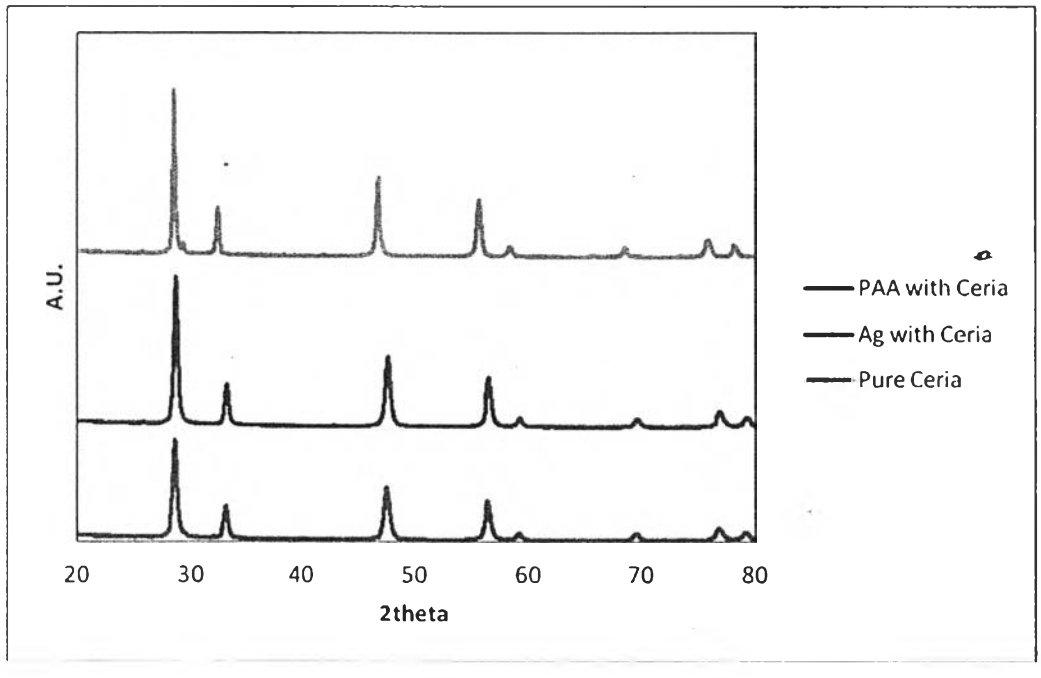

Figure G2 Show the XRD graph of CeO_2, CeO_2 with Ag nanoparticles and CeO_2 synthesized by using 20 mM PAA

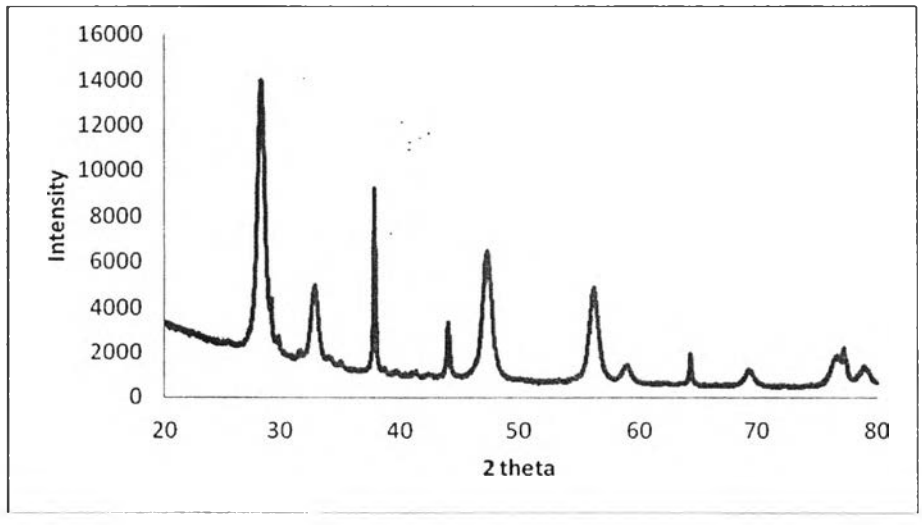

Figure G3 Show the XRD graph of CeO_2 with Ag nanoparticles with ratio between CeO_2:Ag nanoparticles is 1:1

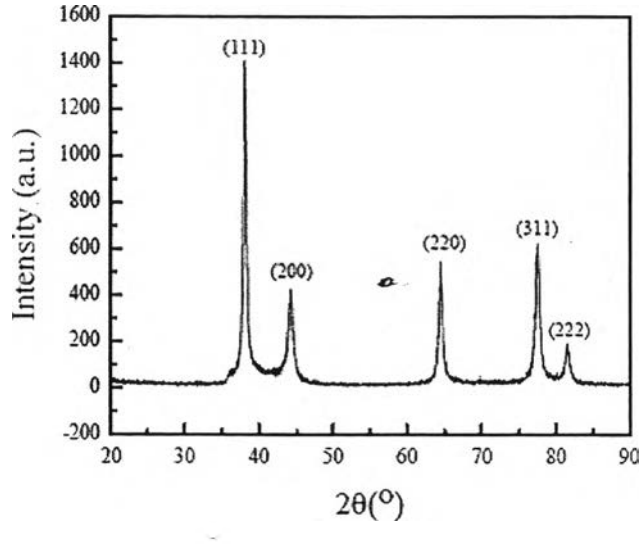

Figure G4 Show the standard XRD graph of Ag nanoparticles (Wong, C.P., 2003)

Appendix H Show the SEM image of photo-catalyst

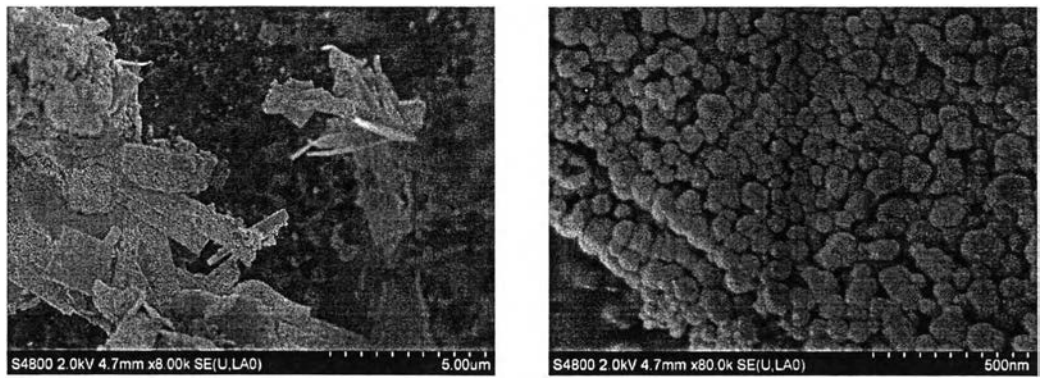

Figure H1 Show the SEM image of pure CeO_2 synthesized without polyelectrolytes at 8,000X and 80,000X

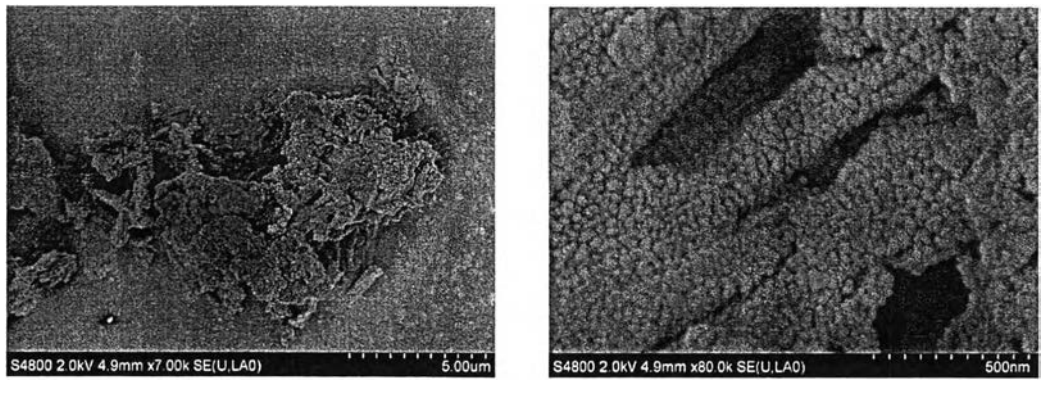

Figure H2 Show the SEM image of pure CeO_2 synthesized with PAA at 8,000X and 80,000X

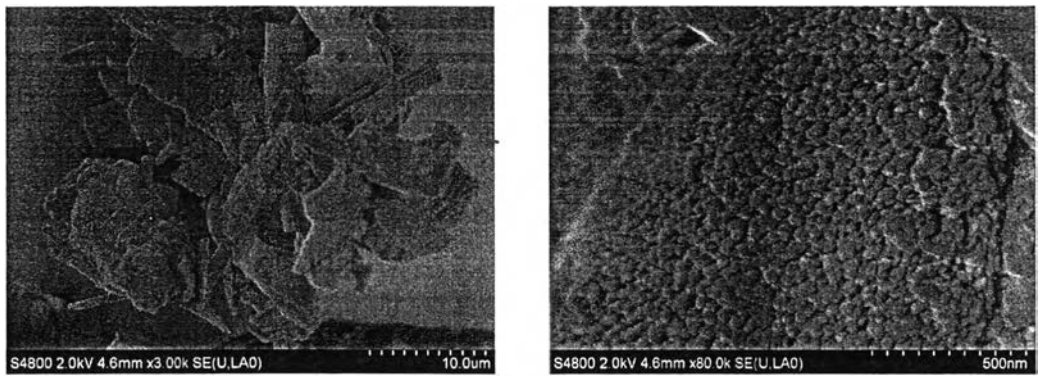

Figure H3 Show the SEM image of pure CeO_2 synthesized with PDADMAC at 8,000X and 80,000X

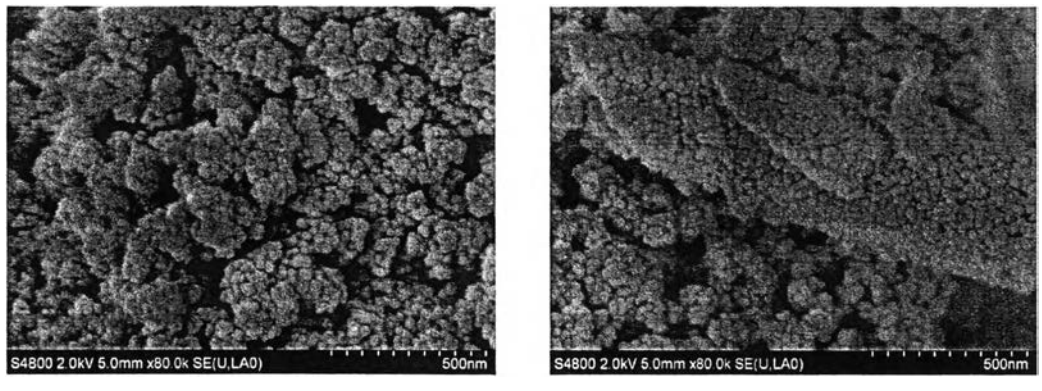

Figure H4 Show the SEM image of pure CeO_2 synthesized with COPSS at 8,000X and 80,000X

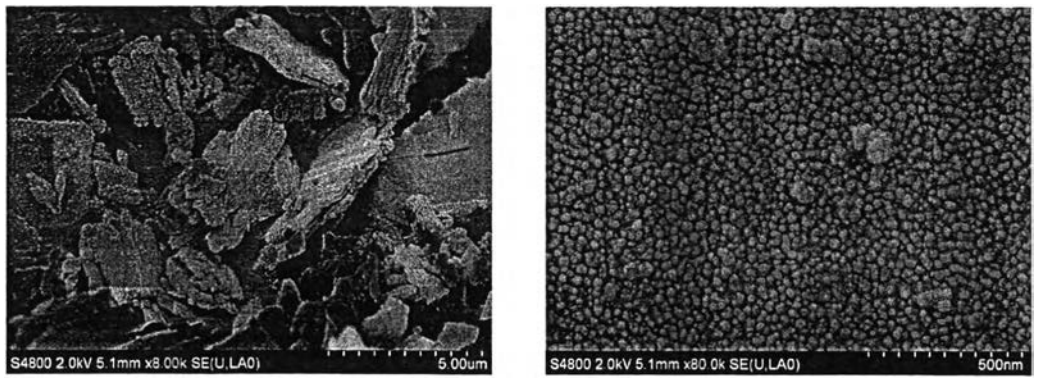

Figure H5 Show the SEM image of pure CeO_2 synthesized with PSS at 8,000X and 80,000X

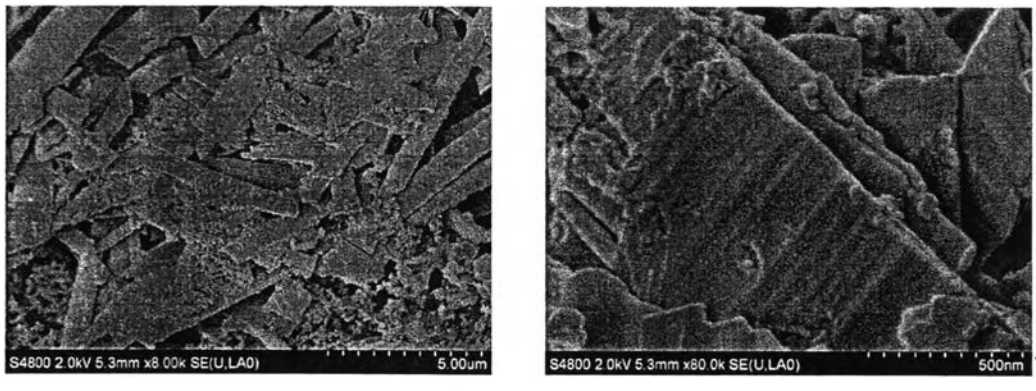

Figure H6 Show the SEM image of $Ce(OH)CO_3$ synthesized without polyelectrolytes at 8,000X and 80,000X

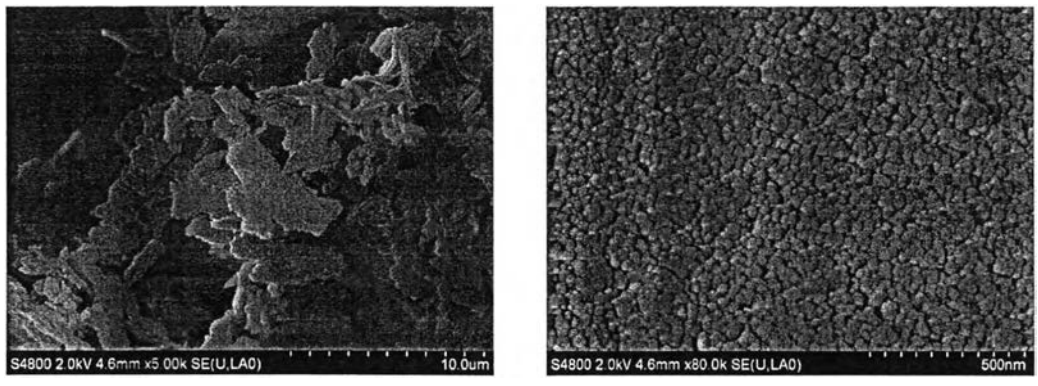

Figure H7 Show the SEM image of CeO_2 synthesized at the surface of Ag nanoparticles (1 mM $AgNO_3$) at 8,000X and 80,000X

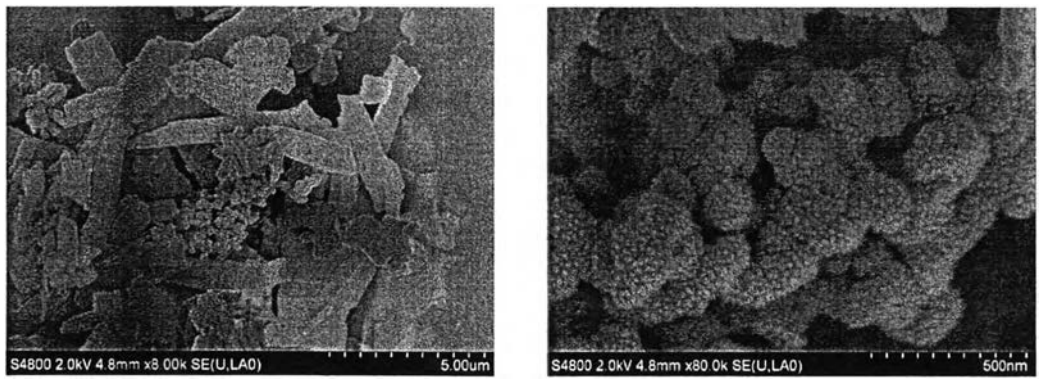

Figure H8 Show the SEM image of CeO_2 synthesized at the surface of Ag nanoparticles (5 mM $AgNO_3$) at 8,000X and 80,000X

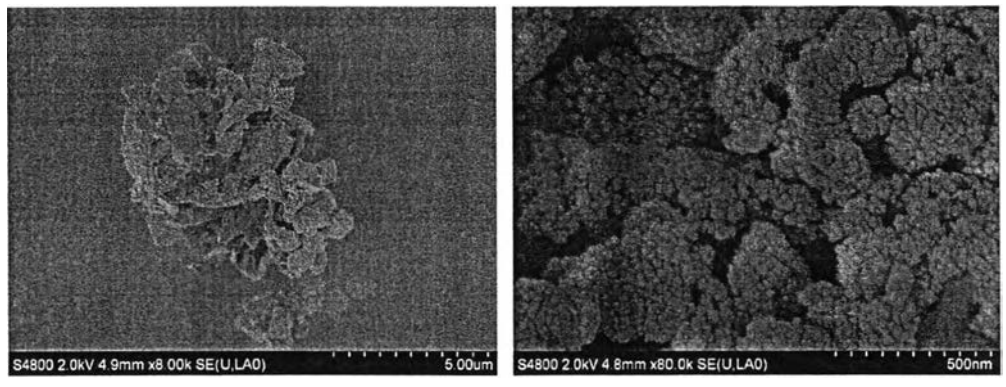

Figure H9 Show the SEM image of CeO_2 synthesized at the surface of Ag nanoparticles (10 mM $AgNO_3$) at 8,000X and 80,000X

CURRICULUM VITAE

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2010-2011: Senior tutor in Physical for first year student, Petrochemical and Polymeric materials, Silpakorn University

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Proceeding :

1. Chavalitkul, J., and Dubas, S.T. (2015, April 21st) Synthesis of Cerium oxide with Ag nanoparticles for photo-catalytic application. Proceeding of the 21st PPC symposium on Petroleum, Petrochemicals and Polymers, Bangkok, Thailand

Presentation :

2. Chavalitkul, J., and Dubas, S.T. (2015, April 21st) Synthesis of Cerium oxide with Ag nanoparticles for photo-catalytic application. Paper presented at the 21st PPC symposium on Petroleum, Petrochemicals and Polymers, Bangkok, Thailand