CHAPTER IV
POLYELECTROLYTES ASSISTED SYNTHESIS OF GOLD/CERIA CATALYST FOR CO REMOVAL

4.1 Abstract

Ceria support was successfully synthesized by using anionic polyelectrolyte as a capping agent. In this work, the effects of capping agent concentration and synthesis method used on ceria particle size was investigated by using various concentrations of poly(4-styrenesulfonic acid-co-maleic acid) (PSS-co-MA) under magnetic stirring or sonication. The silver/ceria was prepared via sodium borohydride reduction and converted to gold/ceria via the redox reaction in an attempt to reduce amount of gold used compared to conventional catalyst preparations. Cerium(III) nitrate hexahydrate, silver nitrate, and hydrogen tetrachloroaurate(III) acid were used as the sources of cerium, silver, and gold, respectively. The prepared catalysts were characterized by particle size analyzer, nitrogen adsorption-desorption, FTIR, XRD, and AAS. The catalytic activity and selectivity of the catalysts were also studied. The experimental results showed that the particle size of ceria was affected by the synthesis method and PSS-co-MA concentration. The increase in PSS-co-MA concentration induced a more negatively charged spread over the ceria surface to stabilize the sphere in solution. The smallest ceria particles (0.58±0.01 micron) were obtained by using 10 mM PSS-co-MA under magnetic stirring.

Keywords: Polyelectrolyte, Ceria, Gold, Silver, CO removal

4.2 Introduction

Polymer electrolyte membrane fuel cell (PEMFC) has been developed during the last decade and become an interesting fuel cell in the application of power generation [1-4]. However, the hydrogen fuel, which is a source of power, usually contain 0.3-1% of carbon monoxide (CO) [5] and the anode of PEMFC is restricted by the small amounts of this carbon monoxide in the hydrogen rich stream.

There are several approaches to remove CO, including selective membrane [6], catalytic methanation [7], and preferential oxidation of CO in H_2-rich stream (PROX) [8, 9]. Among the three methods, PROX appears to be the most promising one because of its ability to remove very small amounts of CO from the gaseous stream to a ppm level. Metal nanoparticles are particularly attractive catalysts for CO oxidation, which are usually immobilized on the supports such as CeO_2 [10-13], SiO_2 [14, 15], TiO_2 [16, 17] and Al_2O_3 [18, 19] (e.g. Ag/CeO_2, Ag/SiO_2, Au/TiO_2 and Pt/Al_2O_3). Ceria is one of the most effective supports for CO oxidation due to its redox properties allowing high oxygen mobility [11]. The catalytic activity in PROX reaction of gold catalysts on various type of oxide supports including TiO_2, CeO_2, Co_3O_4 and Co_3O_4–CeO_2 mixed oxide were studied by Liotta and co-workers [20]. The same high CO conversion value of 76% and 80% for Au/CeO_2 and Au/Co_3O_4–CeO_2, respectively, were obtained at 100 °C. In 2006, ceria-supported gold catalysts for room temperature oxidation of CO to CO_2 were prepared by Pillai and Deevi [21] by using deposition-precipitation technique, but the catalysts showed low surface area. In 2007, Zhang and co-workers [22] found that silver (Ag) could enhance the oxidative properties of ceria while studying Ag/CeO_2 prepared by impregnation method. However, Ag/CeO_2 catalyst is still inconvenience for practical use due to their low surface area and easy to oxidize when exposed to air. To overcome this problem, anionic polyelectrolytes, which have carboxylate group, will be used as a chelating ligand for stabilize CeO_2 supports. The Ag/CeO_2 was further prepared via sodium borohydride reduction and converted to Au/CeO_2 via the redox reaction in an attempt to reduce amount of gold used compared to conventional catalyst preparations. In this study, poly(4-styrenesulfonic acid-co-maleic acid) sodium salt or PSS-co-MA will be used to capped the CeO_2 particles and decreasing the size of oxide particles down to submicron range. This technique can produce ceria supports (nano or micrometer) with highly tunable surfaces properties.

The purposes of this work are to synthesize CeO_2 supports by using anionic polyelectrolyte as a capping agent and to prepare Ag/CeO_2 and Au/CeO_2 for use as catalyst for CO minimizing in PEMFC. The effect of synthesis methods and polyelectrolyte concentrations on CeO_2 particle size are also studied in this work. Moreover, the catalytic activity of Au/CeO_2 catalyst in CO oxidation and methanol reforming reactions are studied, as well.

4.3 Experimental

4.3.1 Materials

Poly(4-styrenesulfonic acid-co-maleic acid) sodium salt with 1:1 styrenesulfonic acid : maleic acid mole ratio (1:1 PSS-co-MA, M_w ~20000, Sigma-Aldrich, USA), poly(4-styrenesulfonic acid-co-maleic acid) sodium salt with 3:1 styrenesulfonic acid : maleic acid mole ratio (3:1 PSS-co-MA, M_w ~20000, Sigma-Aldrich, USA), cerium (III) nitrate hexahydrate ($Ce(NO_3)_3.6H_2O$, 99.5%, Acros Organics, USA), silver nitrate ($AgNO_3$, 99.8%, Sigma-Aldrich, USA), gold (III) chloride trihydrate ($HAuCl_4.3H_2O$, 99.9%, Sigma-Aldrich, USA), sodium borohydride ($NaBH_4$, Fisher Scientific, UK) and sodium carbonate anhydrous (Na_2CO_3, 99.5%, Carlo Erba, France) were used without further purification.

4.3.2 Synthesis Method

4.3.2.1 Chemical Preparation

De-ionized water was used as solvent for all solutions. A desired amount of $Ce(NO_3)_3.6H_2O$ was dissolved in de-ionized water to obtain a concentration of 10 mM. The solution of 1:1 PSS-co-MA anionic polyelectrolyte at concentration of 0.5, 1, 5, 10, 50 and 100 mM was prepared for use as capping agent. A sodium carbonate aqueous solution at concentration of 0.1 M was used as the precipitating agent.

4.3.2.2 Synthesis of Ceria Support

Two methods of the support preparation, quick mixing and drop-by-drop, were used in this work to investigate the effect of preparation method on ceria particle size.

4.3.2.2.1 Quick Mixing

An aqueous solution of 10 mM $Ce(NO_3)_3.6H_2O$ was immediately mix with 0 mM and 10 mM of 1:1 PSS-co-MA solution under gentle stirring by using a magnetic stirrer. The mixed aqueous solution was kept at pH 9.0 by adding a sodium carbonate aqueous solution and aging at 60 °C for 1 hour.

4.3.2.2.2 Drop-by-drop

An aqueous solution of 10 mM $Ce(NO_3)_3.6H_2O$ was poured into burette and then added dropwise to a PSS-co-MA solution at concentration of 0 mM and 10 mM under gentle stirring by using a magnetic stirrer. The mixed aqueous solution was kept at pH 9.0 by adding a sodium carbonate aqueous solution and aging at 60 °C for 1 hour.

To examine the effect of the sonochemical method, an ultrasonic instrument was used as a replacement for the magnetic stirrer. After that, the white precipitate of ceria was filtered and washed by deionized water. The sample was then dried overnight at 100 °C. Moreover, the various concentration of 1:1 PSS-co-MA solution (0, 0.5, 1, 5, 10, 50, and 100 mM) was used to investigate the effect of polyelectrolyte concentrations on the size of ceria support.

4.3.2.3 Synthesis of Gold/Ceria Catalyst

The prepared ceria was suspended in an aqueous solution of 1 mM $AgNO_3$, followed by $NaBH_4$ reduction. The Ag/CeO_2 catalyst was washed by deionized water to remove excess ions and then dried overnight at 100 °C. The Au/CeO_2 catalyst was further prepared by adding the Ag/CeO_2 powder to an aqueous solution of 1 mM $HAuCl_4$ under gentle stirring at room temperature. The Au/CeO_2 catalyst was washed by deionized water and then dried overnight at 100 °C. For comparison, the Au/CeO_2 catalyst with 3:1 PSS-co-MA also prepared by using the same procedure.

4.3.3 Materials Characterization

The particle size distribution of ceria support was characterized on a Malvern Mastersizer X Particle Size Analyzer (PSA). The average size of ceria support particles was also calculated. The X-ray diffraction (XRD) of catalysts were recorded on a Rigaku Smartlab® and CuKα source at 40 kV and 30 mA in a range of

$2\theta = 20-80°$ with a scanning speed of 2°/min. The Brunauer–Emmet–Teller (BET) method on a Quantasorb Jr. (Autosorb-1) was used to measure the surface area of Ag/CeO_2 and Au/CeO_2 catalysts. Prior to each analysis, the product was degassed at 200 °C for 12 h. Varian, SpectrAA 300 Atomic absorption spectrophotometer (AAS) was used to determine the silver and gold contents on the ceria support. A Nicolet 6700 Fourier transform infrared spectrometer (FTIR) was used to collect the spectra and the wavenumber range of the functional group of ceria support and catalysts.

4.3.4 Activity Study

The catalytic activity measurements of Au/CeO_2 catalysts in CO oxidation were followed Sakwarathorn and co-workers' method [27] by using the packed-bed quartz U-tube reactor with a 0.6 mm inner diameter and a 100 mg sample of each catalyst was packed between two layers of glass wool. The activity was observed at various reaction temperatures over the range of 50 – 190 °C. The feed stream contained 40% H_2, 1% O_2 and 1% CO in helium balance. These measurements were done under atmospheric pressure in a continuous flow with a total flow rate of 50 mL/min. The reactant and product gases were detected by an on-line gas chromatograph. The catalytic activity of Au/CeO_2 catalysts in methanol reforming was also collected at various reaction temperatures over the range of 200 – 400 °C followed Pojanavaraphan and co-workers' method [23]. A mixture of methanol and distilled water was injected to a vaporizer at a rate of 1.5 mL/h. A vapor of methanol and steam produced from a vaporizer was mixed with helium carrier gas for carrying the reactant gases to mix with oxygen before entering the catalytic reactor. The gas hourly space velocity was kept at 30000 mL/g-cat.h and the total flow rate was 50 mL/min under pressure of 1 atm. The reactant and product gases were detected by an on-line gas chromatograph, as well.

4.4 Results and Discussion

4.4.1 Effect of Synthesis Method on Ceria Support

To study the effect of the synthesis method on the particle size of ceria support, the quick mixing and drop-by-drop method were used with magnetic stirring or sonication. In addition, the effect of polyelectrolyte concentration on ceria particle size was also investigated. The average particle size of prepared ceria supports are shown in Table 4.1 and Figure 4.1.

Table 4.1 The average particle size of ceria supports prepared by using different method with 0 and 10 mM polyelectrolyte

Synthesis method		Average particle size of ceria (μm)	
		0 mM PSS-co-MA	10 mM PSS-co-MA
Quick mixing	magnetic stirring	2.16 ± 0.03	0.58 ± 0.01
	sonication	0.91 ± 0.08	3.80 ± 0.21
Drop-by-drop	magnetic stirring	3.86 ± 0.18	0.59 ± 0.03
	sonication	0.76 ± 0.01	8.05 ± 0.06

From the results of the particle size analyzer, the synthesis method has a significant effect on the average particle size of ceria support. In the absence of polyelectrolyte capping agent, the quick mixing and the drop-by-drop method under sonication gave smaller ceria particle compared to those synthesized under magnetic stirring due to the high energy dissipation of ultrasonic to disperse ceria particle. On the other hand, the smallest particle size of ceria support with 10 mM polyelectrolyte was obtained by using quick mixing and drop-by-drop method with constant magnetic stirring while the prepared ceria under sonication showed larger particle size. This may be because of polymer bridging and facilitating agglomeration during sonication, not allowing the ceria dispersion to occur fully.

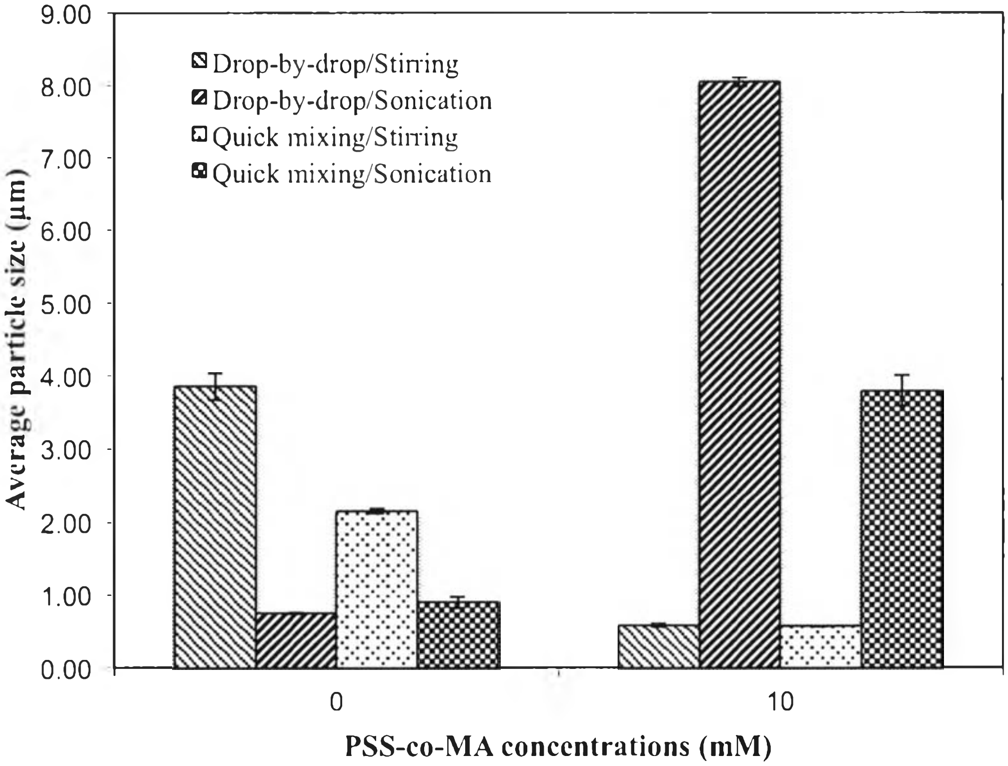

Figure 4.1 Plot of the ceria average particle size prepared by 0 and 10 mM polyelectrolyte with different method.

The size distributions of ceria supports prepared by different method are shown in Figure 4.2 and Figure 4.3. It was found that the small particle with less than 1 micron diameter was obtained by using quick mixing and drop-by-drop method under gentle stirring with magnetic stirrer while sonication gave various size of caria support which major size are large particle (1-10 micron). Hence, the suitable synthesis method chosen was quick mixing under magnetic stirring since it is the simplest method.

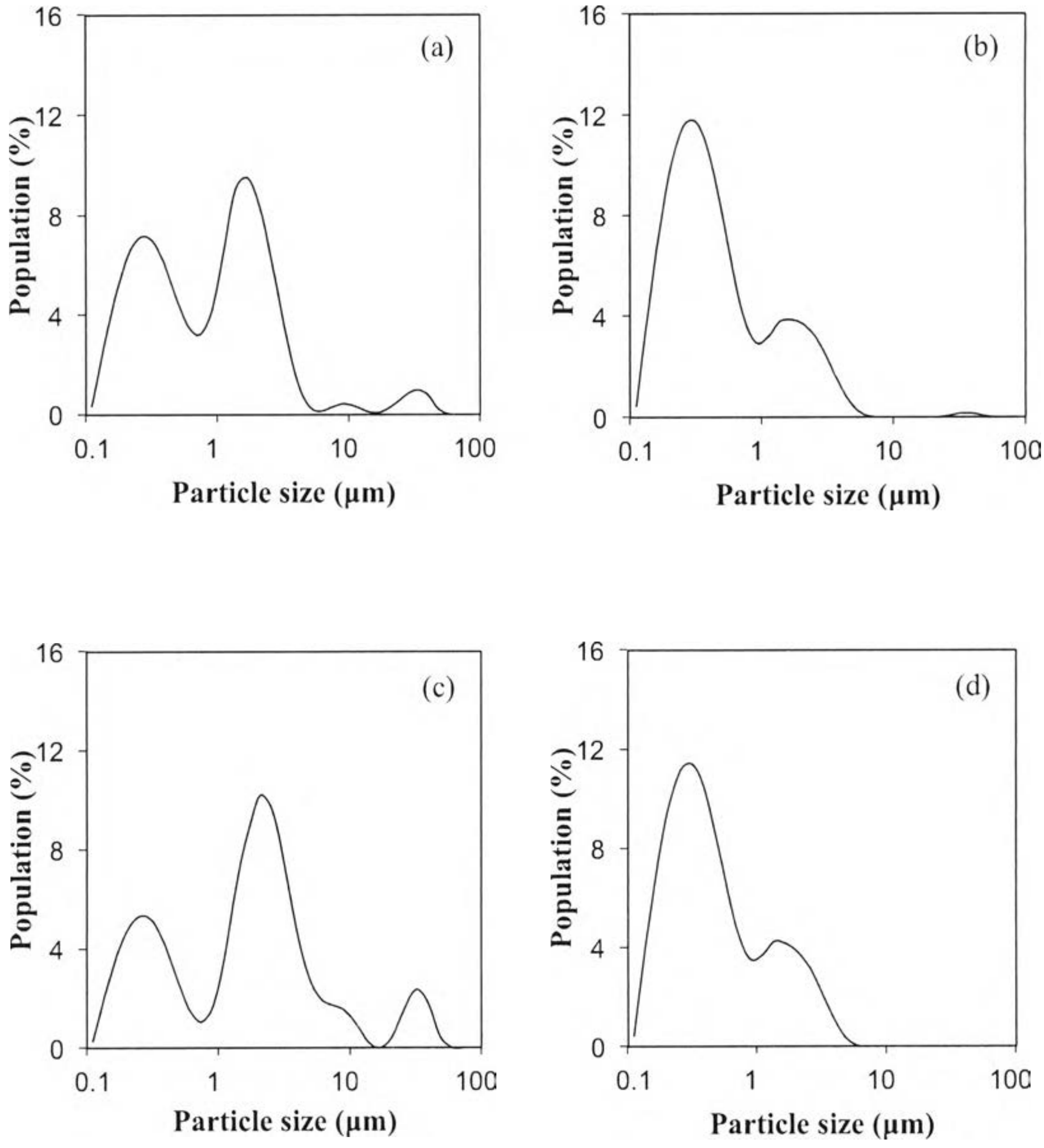

Figure 4.2 Particle size distribution of ceria support prepared by using 0 mM polyelectrolyte with different method: (a) quick mixing under magnetic stirring, (b) quick mixing under sonication, (c) drop-by-drop under magnetic stirring, and (d) drop-by-drop under sonication.

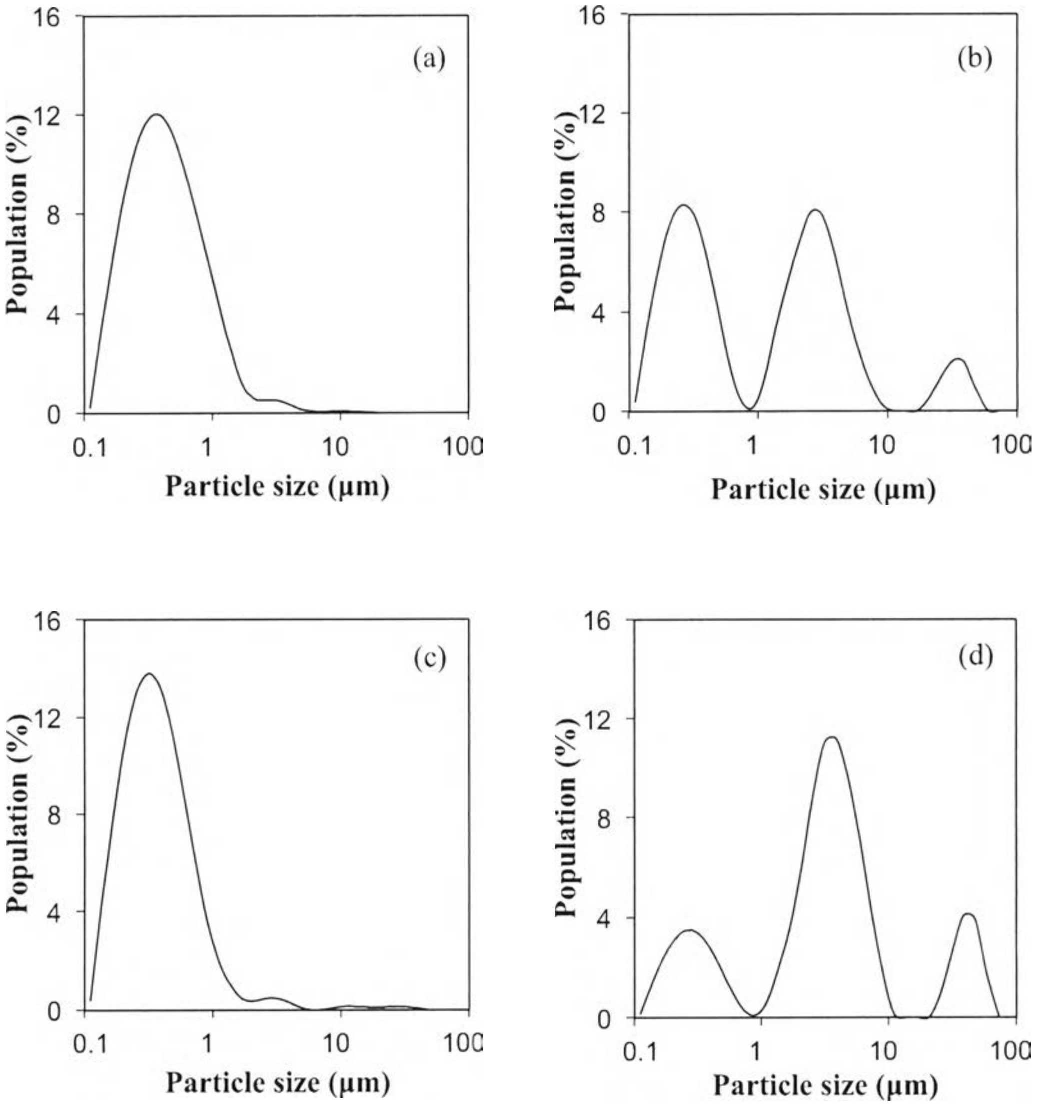

Figure 4.3 Particle size distribution of ceria support prepared by using 10 mM polyelectrolyte with different method: (a) quick mixing under magnetic stirring, (b) quick mixing under sonication, (c) drop-by-drop under magnetic stirring, and (d) drop-by-drop under sonication.

As shown in Figure 4.2 and Figure 4.3, the amount of ceria particles with less than 1 micron were increased while the amount of large particles (larger than 1 micron) were decreased by using PSS-co-MA as a capping agent under magnetic stirring. It confirmed that the presence of anionic polyelectrolyte results in an increase of the surface charge and could stabilize ceria particles through electrostatic repulsion. In contrast, the presence of PSS-co-MA in ceria support preparation under sonication results in an increasing of ceria particles with larger than 1 micron. This probably because of more absorbed ceria particle on polyelectrolyte chain. The ultrasonic wave of sonication might be accelerating cerium ions to interact with anionic polyelectrolyte and caused rapidly growing of ceria particles. Thus, the sonication method should be used to synthesize ceria support in the absence of polyelectrolyte.

4.4.2 Effect of Polyelectrolyte Concentration on Ceria Support

To study the effect of polyelectrolyte concentration on the particle size of ceria support, the anionic polyelectrolyte which contains acrylate functional group was chosen because of their ability to interact with cerium cation. Ceria support was prepared by mixing an aqueous solution of cerium nitrate precursor with various concentrations of PSS-co-MA, including 0.5, 1, 5, 10, 50, and 100 mM, under gentle stirring with magnetic stirrer. The size distributions of ceria supports are shown in Figure 4.4.

The size distribution of ceria support that was prepared by 0.5 mM PSS-co-MA shows two main groups of particles, one is small particles (less than 1 micron) and another one is larger particles (1-10 micron). It was found that the amounts of small particles increased while the amounts of large particles decreased with increasing PSS-co-MA concentration because of more acrylate group to stabilize ceria particle. On the other hand, high concentration (50 and 100 mM) of PSS-co-MA polyelectrolyte increased the ceria support particle size probably because of bridging of polymer chain.

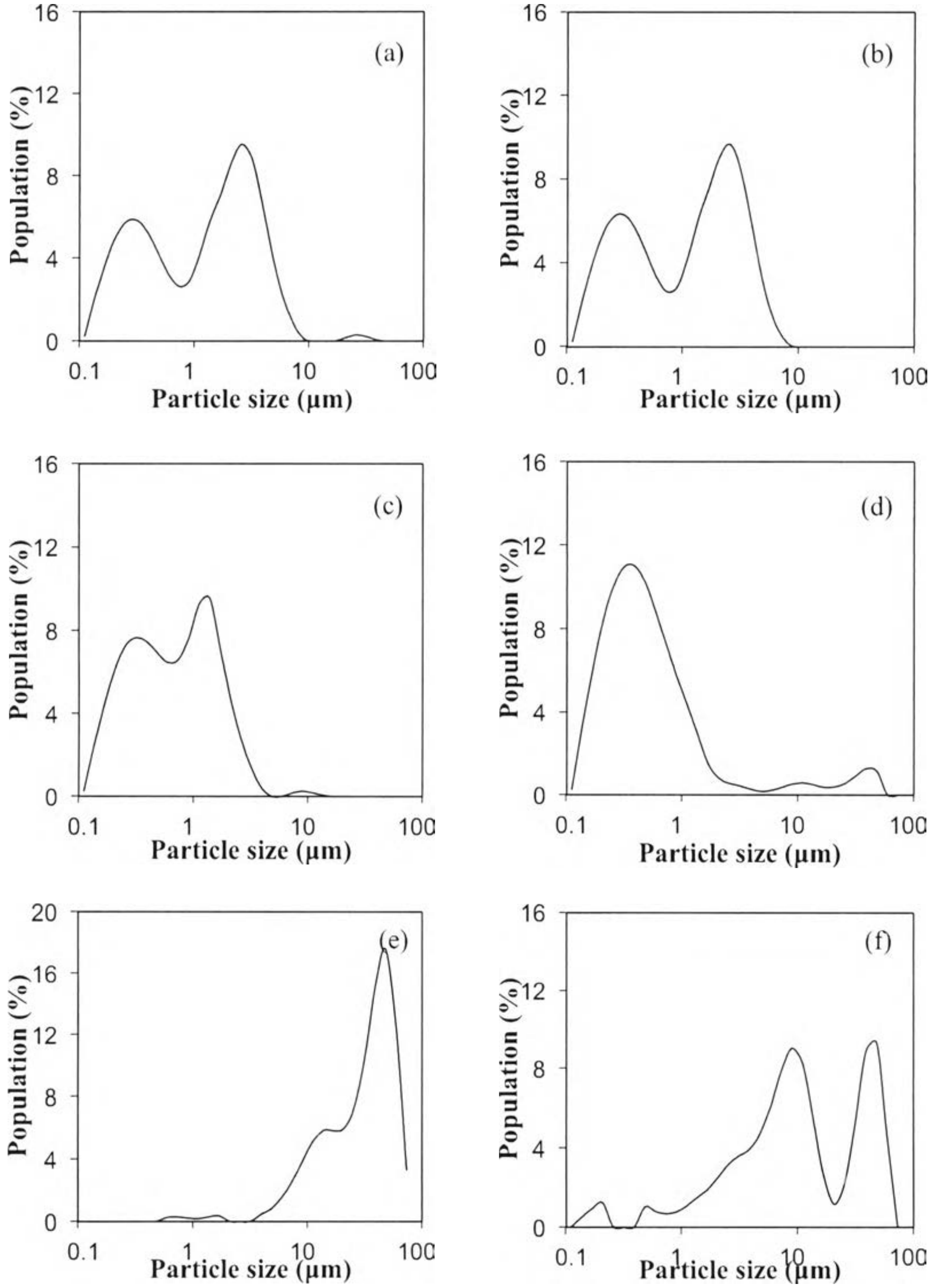

Figure 4.4 Particle size distribution of ceria support prepared by quick mixing under magnetic stirring with various concentrations of polyelectrolyte: (a) 0.5 mM, (b) 1 mM, (c) 5 mM, (d) 10 mM, (e) 50 mM, and (f) 100 mM.

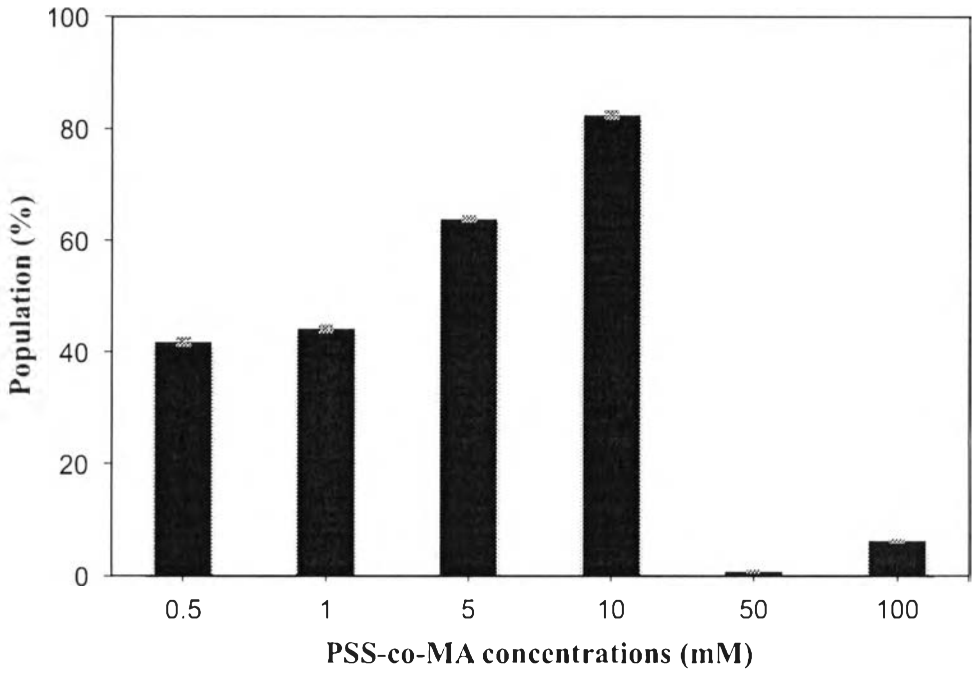

Figure 4.5 Plot of the % particle content of ceria with less than 1 micron diameter for various polyelectrolyte concentrations.

The ceria support with less than 1 micron diameter was obtained by using PSS-co-MA as a capping agent. The experimental results from the Particle Size Analyzer showed that the particle size of ceria was affected by the PSS-co-MA concentration as shown in Figure 4.5. The ion pairs formation between ceria ion and acrylate group of PSS-co-MA leads to small particle size of ceria support by prevent the growing of ceria crystal. The increase in PSS-co-MA concentration from 0.5 to 10 mM caused more negatively charged spread over the ceria surface to produce small particle and stabilize the sphere in solution. Until at 50 and 100 mM of PSS-co-MA, the amounts of small particle decreased and large particle aggregates having a mean size more than 10 micron are formed since polymer bridging fused ceria particle together and form bigger particles. So, it can be conclude that the optimum concentration of PSS-co-MA for synthesize ceria support is 10 mM. Various types of anionic polyelectrolytes, such as sodium alginate and poly(acrylic acid), could also be used as capping agent to produce small sized ceria through electrostatic repulsion.

4.4.3 Catalyst Characterization

Ceria support, silver/ceria and gold/ceria catalysts were identified by FTIR. The FTIR spectra of ceria support prepared by different concentrations of 1:1 PSS-co-MA are shown in Figure 4.6. According to the literature [24-26], the observed FT-IR spectra consist of three zones in the range of 2500–3700, 1200–1700 and 700–1100 cm^{-1}, correspond to the O–H stretching vibration of a hydroxyl bonds or residual water, carbonate species, and carbon-involved species, respectively. The bands located at around 1400 cm^{-1} are assigned to the bending vibration of C–H bonds of the capping agent. The peaks at 1060 and 850 cm^{-1} are attributed to the bending vibration of CO_3^{2-} and the stretching vibration of C–O bonds, respectively. In addition, the band due to the stretching vibration of Ce–O bonds can be seen at around 700 cm^{-1} indicating the formation of CeO_2.

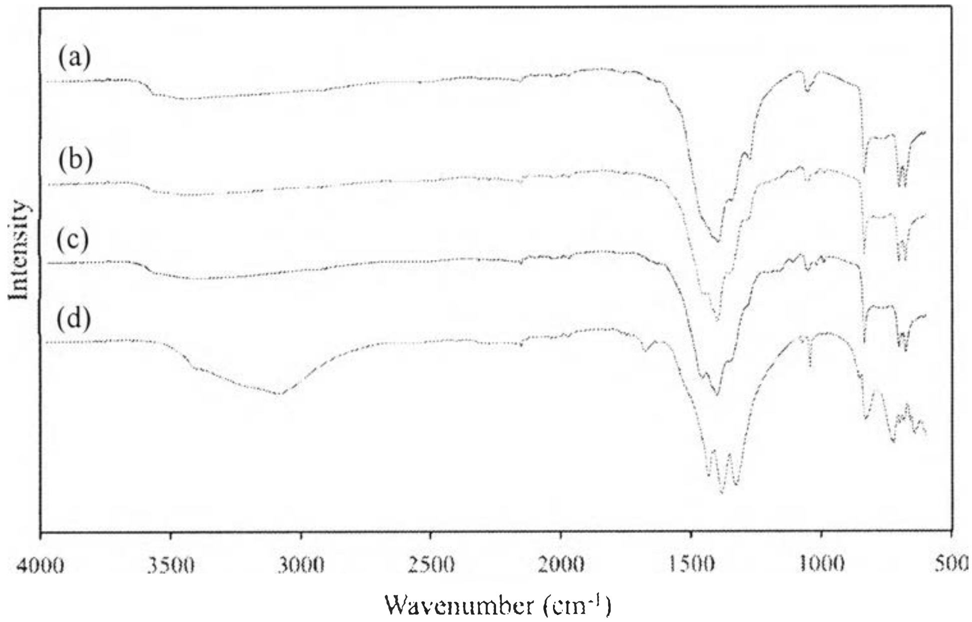

Figure 4.6 FTIR spectra of ceria support prepared by using various concentrations of PSS-co-MA capping agent: (a) 0 mM, (b) 1 mM, (c) 10 mM and (d) 100 mM.

Figure 4.7 illustrates the FTIR spectra of Ag/CeO_2 and Au/CeO_2 capped with 1:1 and 3:1 PSS-co-MA. The data obtained were consistent with those reported previously [27]. The band of the hydroxyl groups stretching vibration in the range of 2500–3700 cm^{-1} was observed. The band in the range of 1200–1700 cm^{-1} confirms the formation of carbonate species, which could generate active sites for the CO oxidation.

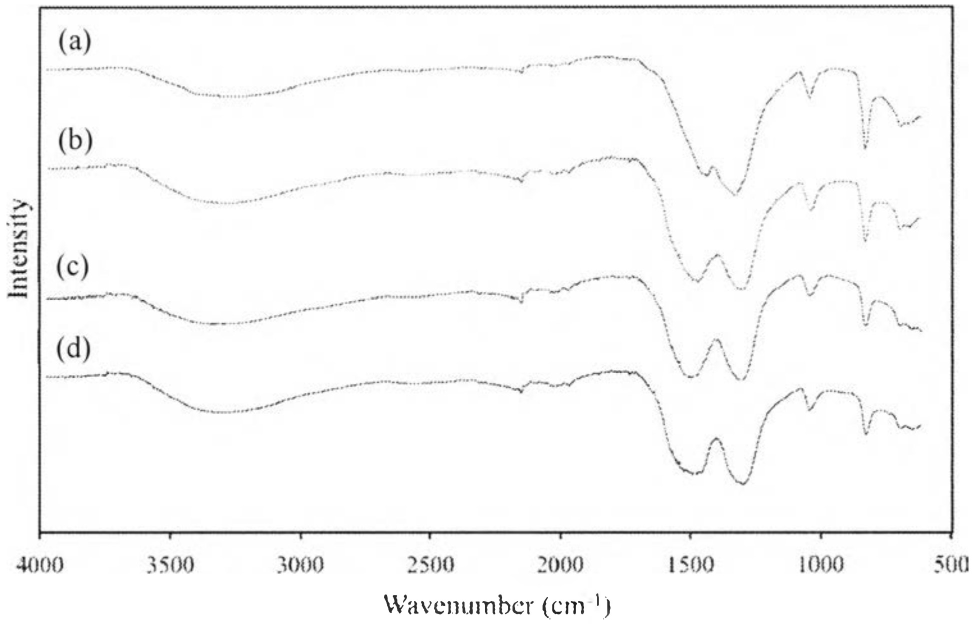

Figure 4.7 FTIR spectra of catalysts prepared by using 10 mM of different type of polyelectrolytes capping agent: (a) Ag/CeO_2 with 1:1 PSS-co-MA, (b) Ag/CeO_2 with 3:1 PSS-co-MA, (c) Au/CeO_2 with 1:1 PSS-co-MA and (d) Au/CeO_2 with 3:1 PSS-co-MA.

The XRD patterns of Ag/CeO$_2$ and Au/CeO$_2$ catalysts are illustrated in Figure 4.8. Both Ag/CeO$_2$ and Au/CeO$_2$ catalysts exhibit the characteristic diffraction peaks of ceria corresponding to (111), (200), (220), (311), (222), (400), and (331) planes. The prepared Ag/CeO$_2$ shows the XRD peaks of Ag (111), Ag (200), Ag (220), and Ag (311) at 2θ of 38.22°, 44.82°, 64.61°, and 77.35°, respectively. Moreover, the peaks correspond to (110), (111), (200), (220), (311), and (222) planes of Ag$_2$O were detected, indicating that the synthesized catalyst contains Ag and Ag$_2$O phases. After HAuCl$_4$ addition, the XRD peaks of Au (111), Au (200), Au (220), and Au (311) appear at 2θ of 38.27°, 44.60°, 64.68°, and 77.55°, respectively, indicating the dispersion of Au over CeO$_2$ support.

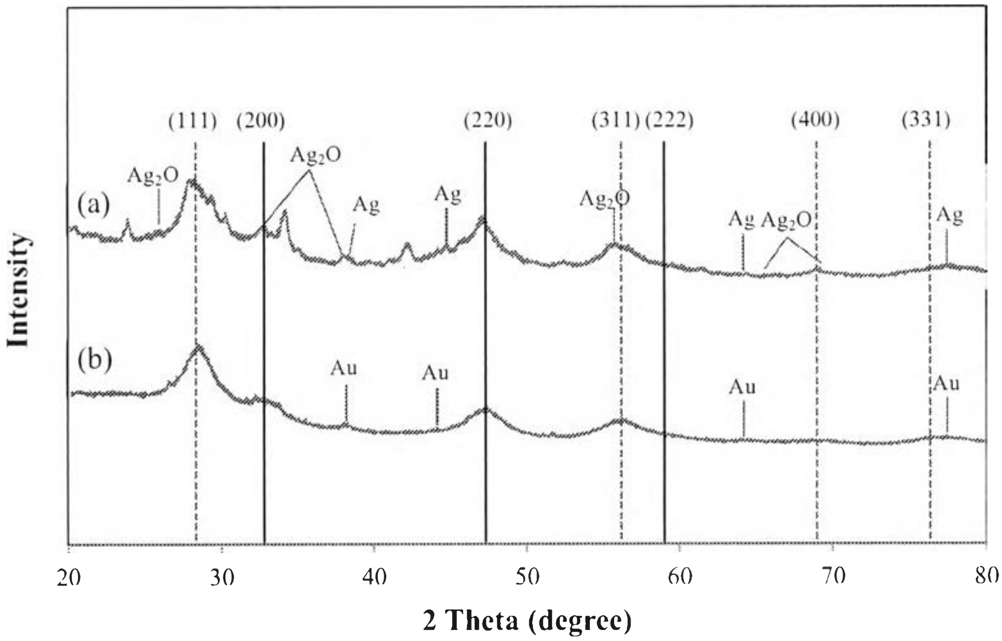

Figure 4.8 XRD patterns of (a) Ag/CeO$_2$ and (b) Au/CeO$_2$ catalysts.

Table 4.2 The metal contents and BET analysis of Ag/CeO_2 and Au/CeO_2 catalysts

Catalyst	Metal loading (%)	BET surface area (m^2/g)
Ag/CeO_2	0.55	78
Au/CeO_2	0.22	110

The actual metal loading of the Ag/CeO_2 and Au/CeO_2 catalysts prepared by using 10 mM of 1:1 PSS-co-MA as a capping agent was analyzed by Atomic Absorption Spectrophotometer (AAS) as shown in Table 4.2. The silver content of the Ag/CeO_2 catalyst was higher than gold content of the Au/CeO_2, which prepared by converted silver on ceria to gold via redox reaction. Silver with no charge being oxidized to form a silver ion. Then, gold ion is being reduced trough the addition of three electrons from silver to form solid gold, according to the following reactions:

$Ag^0 \rightarrow Ag^+ + e^-$ (oxidation)

$Au^{3+} + 3e^- \rightarrow Au^0$ (reduction)

$3Ag^0 + Au^{3+} \rightarrow Au^0 + 3Ag^+$ (redox reaction)

According to XRF results, the Au/CeO_2 catalyst shows very low gold content (0.22%) compare to silver content (0.55%) in Ag/CeO_2. This may result from incomplete redox reaction of silver and gold in unsuitable conditions such as the reaction time, the concentration of metal solution and the pH of solution. Table 4.2 also shows the BET surface area of the Ag/CeO_2 (78 m^2/g) and Au/CeO_2 (110 m^2/g) catalysts. Moreover, the Au/CeO_2 catalyst prepared by using PSS-co-MA shows higher surface area than those prepared by conventional methods [27].

4.4.4 Catalytic Activity of Gold/Ceria

The study of catalytic activity of Au/CeO_2 catalyst was followed Luengnaruemitchai and coworkers' method [27]. To compare the ability of polyelectrolytes capping agent, PSS-co-MA with different molar ratio of sulfonate and maleic group (1:1 and 3:1) were use to prepare the Au/CeO_2 catalysts. The catalytic activity was observed at various reaction temperatures over the range of 50 – 190 °C to obtain the optimum condition of CO oxidation reaction as shown in Figure 4.9 and 4.10.

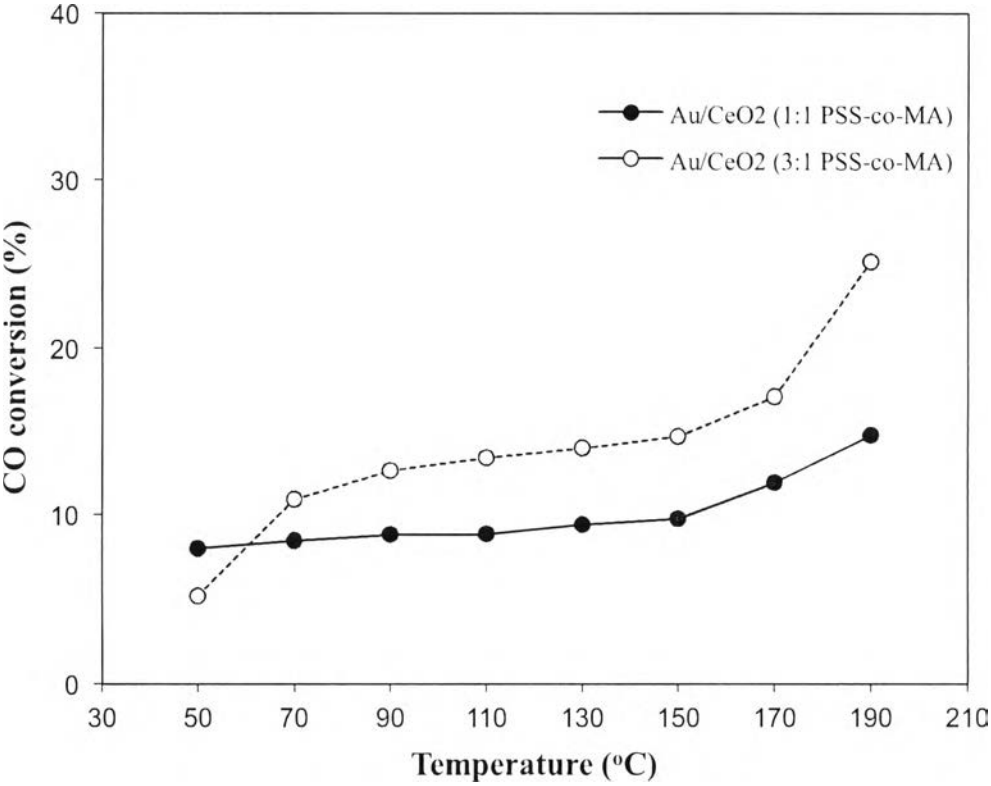

Figure 4.9 Effect of the different polyelectrolytes on the CO conversion of Au/CeO_2 catalysts in CO oxidation reaction.

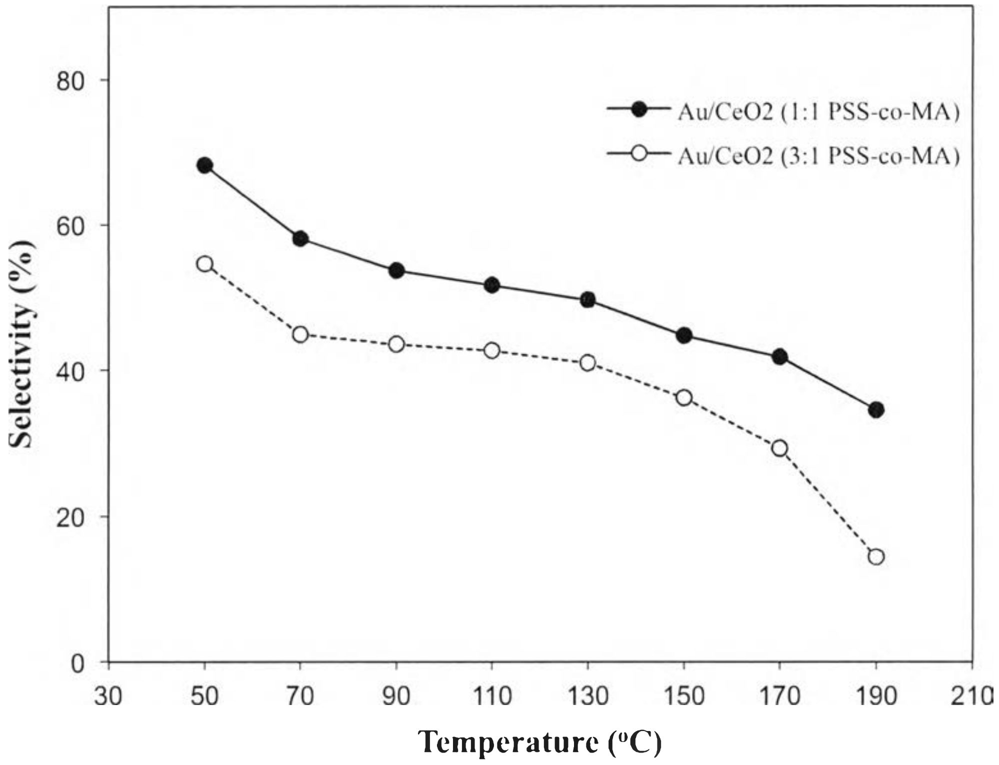

Figure 4.10 Effect of the different polyelectrolytes on the selectivity of Au/CeO_2 catalysts in CO oxidation reaction.

The CO conversions of both catalysts prepared by 1:1 and 3:1 PSS-co-MA gradually increased with the increasing of reaction temperature and give a maximum conversion at 190 °C. In contrast, lower reaction temperature lead to the catalyst having higher selectivity. A maximum selectivity of 68% was achieved at the reaction temperature of 50 °C for the catalyst prepared using 1:1 PSS-co-MA and higher than those reported previously [20, 27]. However, the catalysts prepared by these two capping agents exhibited lower conversion than those prepared without capping agent [20, 27]. The reason may comes from the presence of hydroxyl species from water on the surface of catalysts, which could limit the interfacial redox process and the catalytic activity by block the active sites.

Stream reforming of methanol (SRM) is one of the reactions used to produce high H_2 purity for PEMFC. It is necessary to obtain only trace amount of CO in the product stream due to the requirement in PEMFC. According to the purpose of this work is to minimize the CO concentration in PEMFC, the catalytic activity of Au/CeO_2 in SRM reaction was also studied.

As illustrated in Figure 4.11, there was no reaction occurring at 200 °C and the methanol conversion increased with increasing reaction temperatures from 250 °C to 400 °C due to methanol decomposition at high temperature. A maximum methanol conversion of 69% was achieved at the reaction temperature of 400 °C. Figure 4.12 and Figure 4.13 present the product selectivity of Au/CeO_2 in SRM reaction. It was found that H_2 and CO selectivity increased with reaction temperature whereas CO_2 selectivity decreased with reaction temperature. In terms of product composition, the concentration of H_2 and CO increased with reaction temperature and the highest H_2 yield (34%) was obtained at 400 °C as illustrated in Figure 4.14 and Figure 4.15, respectively. This could be concluded that the Au/CeO_2 catalyst can be used in SRM at high reaction temperature with high catalytic activity. However, our catalyst is found to be less efficient than the literature [28] with the same reason in CO oxidation catalytic study.

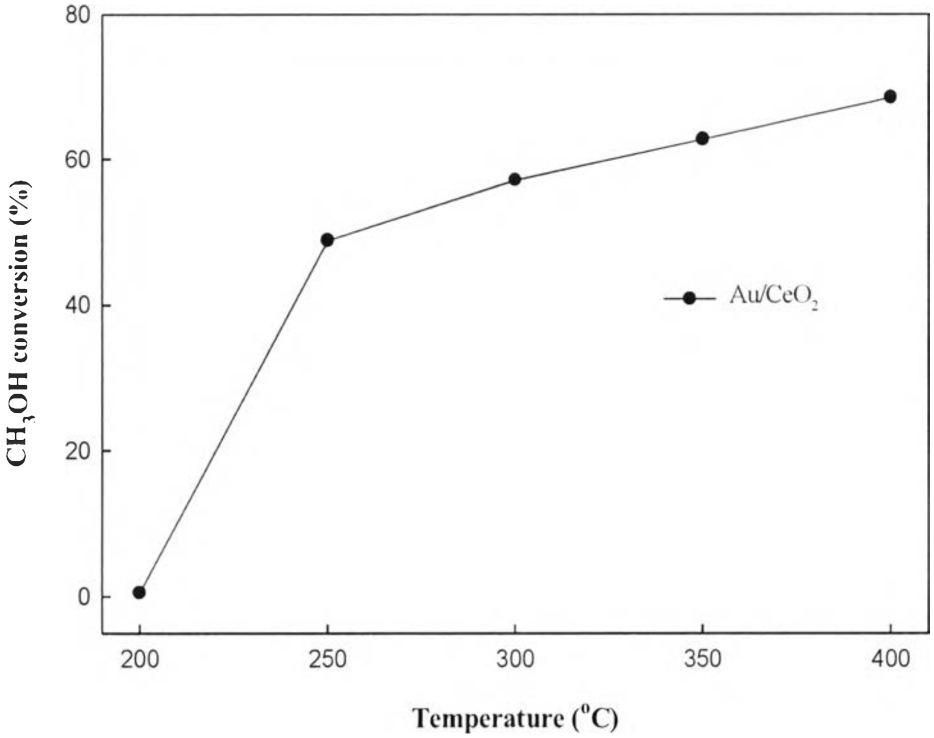

Figure 4.11 Methanol conversion of Au/CeO$_2$ catalyst in methanol reforming at different temperatures.

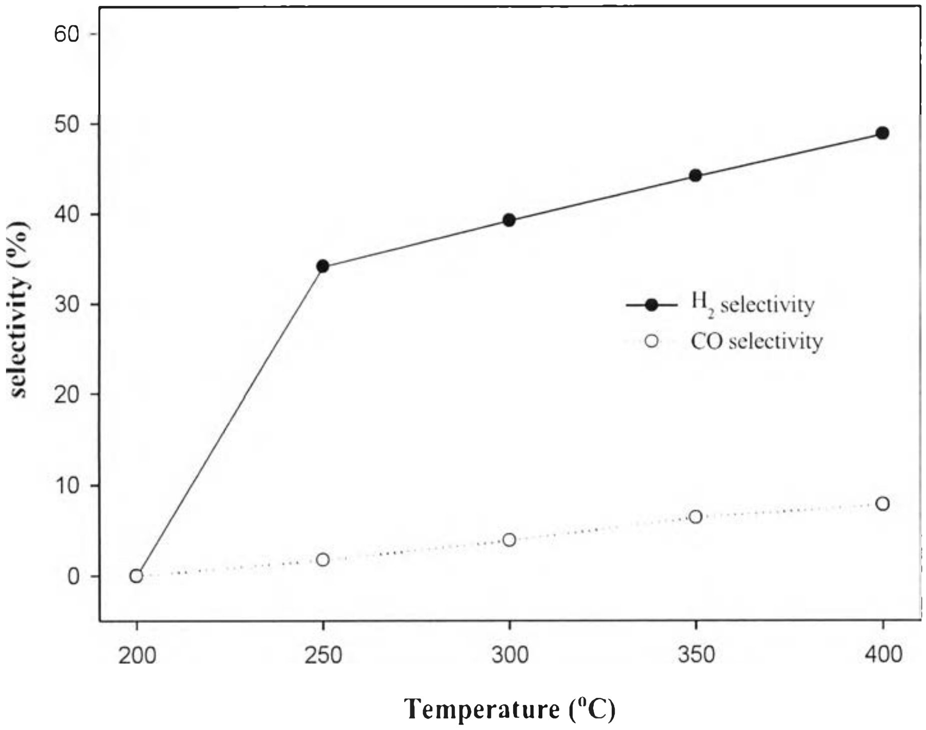

Figure 4.12 H_2 and CO selectivity of Au/CeO_2 catalyst in methanol reforming at different temperatures.

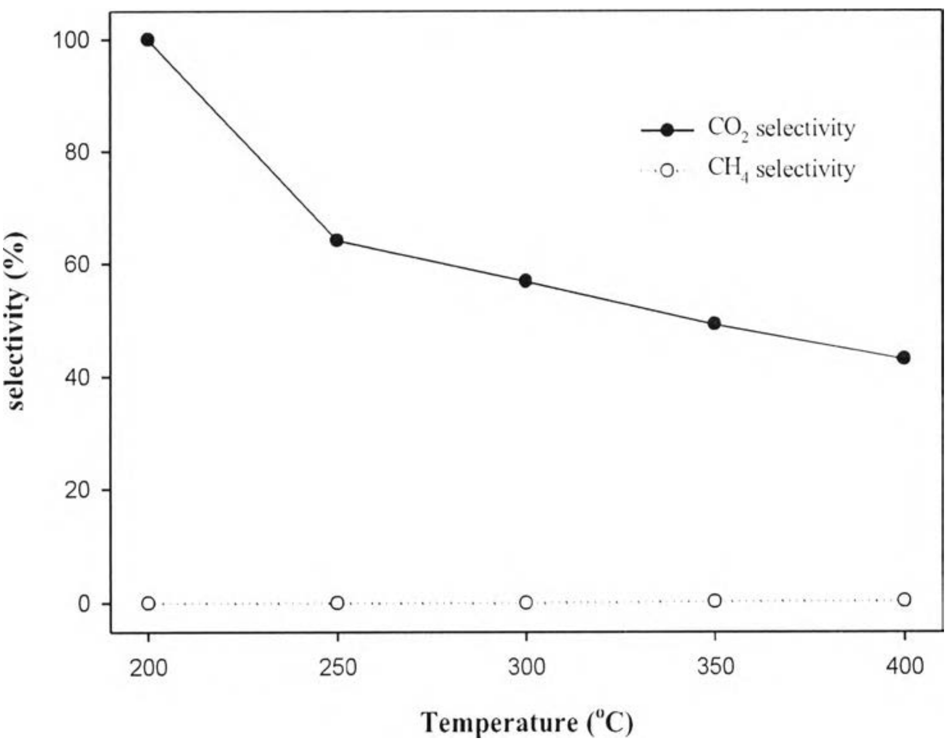

Figure 4.13 CO_2 and CH_4 selectivity of Au/CeO_2 catalyst in methanol reforming at different temperatures.

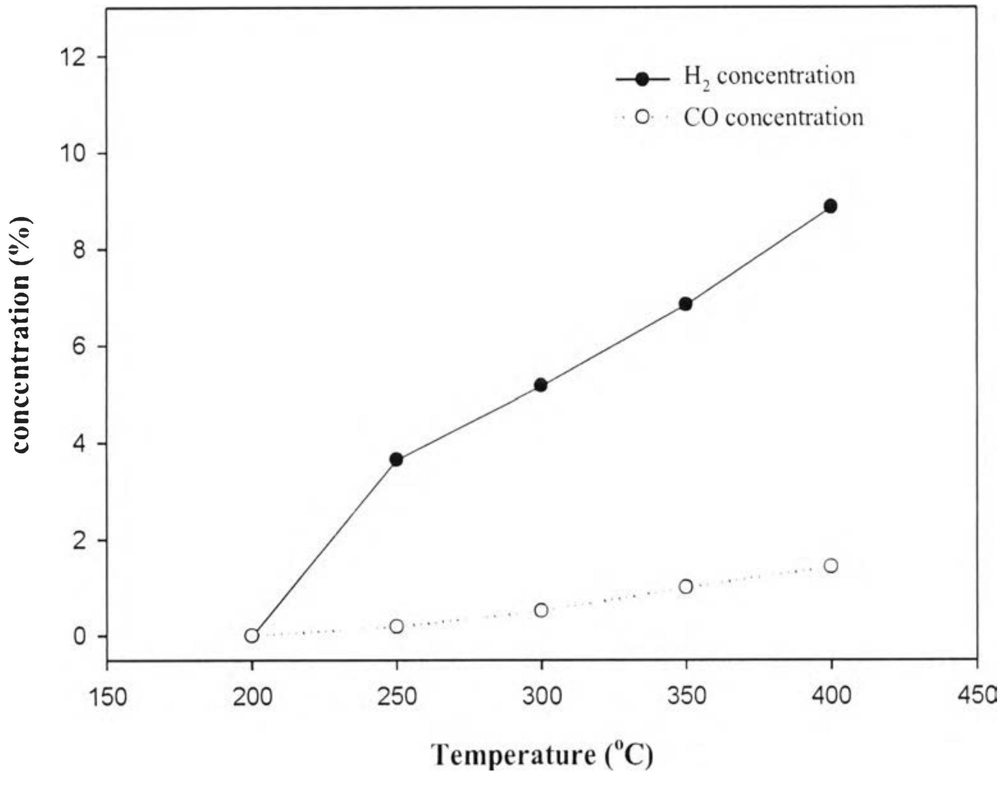

Figure 4.14 Product composition of Au/CeO_2 catalyst in methanol reforming at different temperatures.

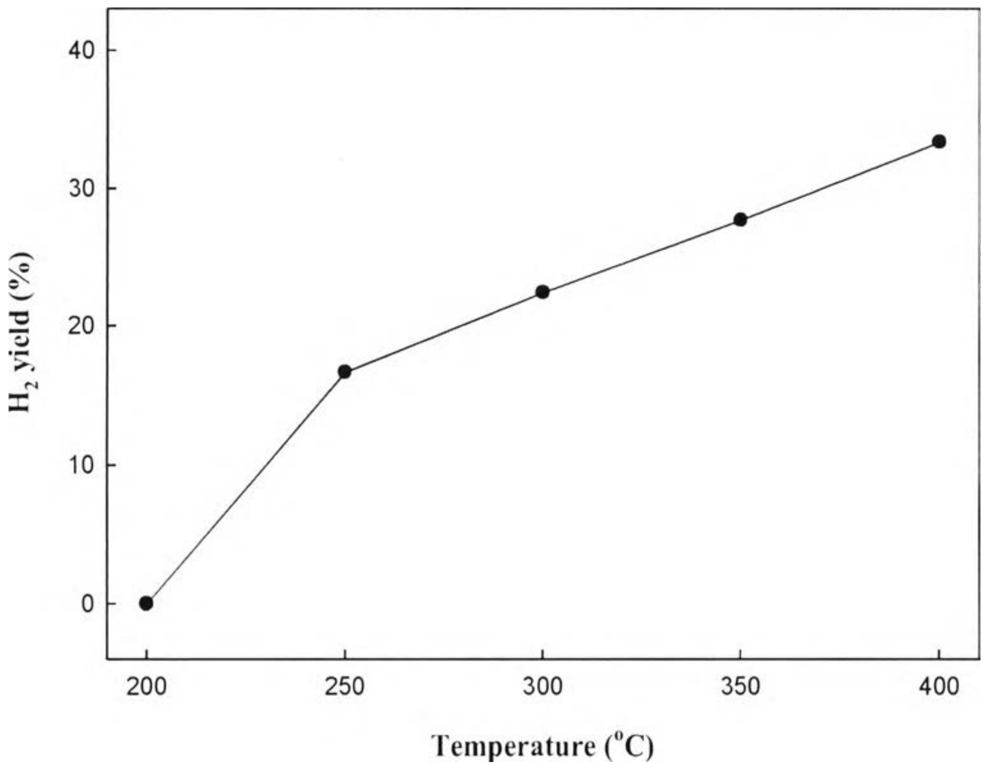

Figure 4.15 Hydrogen yield of Au/CeO_2 catalyst in methanol reforming at different temperatures.

From the results of catalytic activity study, the Au/CeO_2 catalyst shows low CO and methanol conversion in CO oxidation and methanol reforming reaction, respectively. This probably relate to very low gold content deposit on the support, resulting in low coordination active site on surface of the ceria support, and leads to low catalytic activities. So, The effect of metal loading on catalytic activities should be investigated in further study.

4.5 Conclusions

Ceria support was successfully synthesized by using anionic polyelectrolyte, PSS-co-MA, as a capping agent. The smallest ceria particle of 0.58±0.01 micron was obtained by using 10 mM of 1:1 PSS-co-MA under magnetic stirring. This optimum concentration causes negatively charged spread over the ceria surface to stabilizing the sphere in solution. The Ag/CeO_2 was further synthesized via sodium borohydride reduction of Ag^+ on prepared ceria support prior the addition of $HAuCl_3$ for preparing Au/CeO_2 catalyst by redox reaction between Ag/CeO_2 and Au^{3+} ion. The Au/CeO_2 catalyst for CO oxidation resulted in maximum CO conversion of 15% at 190 °C with maximum selectivity of 68% at 50 °C. For methanol reforming, the catalytic activity of Au/CeO_2 catalyst resulted in 69% methanol conversion with 50% H_2 selectivity and 34% H_2 yield at 400 °C reaction temperature.

4.6 Acknowledgments

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