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PII:	\$1566-7367(20)30322-8
DOI:	https://doi.org/10.1016/j.catcom.2020.106246
Reference:	CATCOM 106246
To appear in:	Catalysis Communications
Received date:	30 April 2020
Revised date:	29 October 2020
Accepted date:	17 November 2020

Please cite this article as: W. Tolek, K. Khruechao, B. Pongthawornsakun, et al., Flame spray-synthesized Pt-Co/TiO2 catalysts for the selective hydrogenation of furfural to furfuryl alcohol, *Catalysis Communications* (2020), https://doi.org/10.1016/j.catcom.2020.106246

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Flame spray-synthesized Pt-Co/TiO₂ catalysts for the selective hydrogenation of furfural to furfuryl alcohol

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Abstract

Flame spray-synthesized Pt/TiO₂ and PtCo/TiO₂ catalysts with 0.7 wt% Pt and 0-0.4 wt% Co were studied in the hydrogenation of furfural to furfuryl alcohol (FA) at 50°C and 2 MPa H₂. Particle formation under high temperature flame facilitated high Pt dispersion and formation of Pt-TiO_x interface sites, which were beneficial for furfural conversion to FA. Modifying with Co accelerated rutile phase TiO₂ formation, which strongly diminished hydrogenation activity on the (FSP)-PtCo/TiO₂. On the other

hand, (I)-PtCo/TiO₂ prepared by conventional impregnation, anatase phase TiO₂ was preserved (> 85%) and both furfural conversion and FA selectivity increased upon increasing Co loading.

Keywords: selective hydrogenation; furfural; furfuryl alcohol; Pt/TiO₂; flame spray pyrolysis; Co addition

1. Introduction

Furfural, obtained via acid-catalyzed dehydration of pentose such as xy'ose and arabinose or via fast pyrolysis of biomass, is one of the most promising biomass-derived platforms as a building bloc' in the bio-refinery approach [1, 2]. Selective hydrogenation of furfural has gained much attention for the production of furful vl alcohol (FA), an important intermediate for the manufacturing of lysine, ascorbic acid (vitamin C), plasticizers, dispersing agent, and lubricants and is mainly used in the manufacture of resins, synthetic fibers, and agrochemicals [3]. In furan ind, strial process, copper chromite has traditionally been used as the catalyst for hydrogenation of furfural to FA [2, 3]. However, concern of the environmental toxic impact due to the chromium presence in the catalysts led to the development of chromium free catalysts.

Platinum-based catalysts are known as highly efficient catalysts used in the hydrogenation of furfural to FA because of their ability to hydrogenate the C=O under mild conditions [3-5]. Pt nanoparticles in the range of 3-7 nm were found to favor the hydrogenation of furfural to FA whereas Pt particle size less than 3 nm promoted the decarbonylation of furfural to furan [3, 6]. However, modification of Pt catalysts by alloying [7, 8], adding promoters [7, 9], and by using strong metal-support interaction to

induce electronic effects [8, 10] show significant impact on both activity and selectivity towards FA of the catalysts in furfural hydrogenation. For examples, The metal-support interaction on Pt/TiO_2 induced hydrogen spillover, leading to the formation of furfuryl-oxy intermediate on the titania support [11, 12]. Synergetic effect between Pt and Co on carbon obtained by co-impregnation was reported to be beneficial in furfural hydrogenation and product selectivity can be adjusted depending on the weight ratio of Pt and Co [13, 14].

In this study, monometallic Pt/TiO₂ and bimetallic Pt-Co/TiO₂ were prepared by f ame spray pyrolysis (FSP) and studied in the liquid-phase selective hydrogenation of furfural to FA under mild conditions. The characteristics of Pt-Co/TiO₂ formed by one-step FSP were quite different from those obtained by co-impregnation as ill. trailed by various characterization techniques such as CO pulse chemisorption, H₂-temperature-programmed reduction (H₂ ·TPR), transmission electron spectroscopy (TEM), and Fourier transform infrared (FTIR) spectroscopy of adsorbed CO A structural-activity relationship of these FSP-PtCo/TiO₂ catalysts was proposed.

2. Experimental

2.1 Catalyst preparation

The Pt/TiO₂ (0.7 wt% Pt) and Pt-Co/TiO₂ (0.7 wt% Pt and 0-0.4 wt.% Co) catalysts were prepared by FSP method according to the procedure described in Ref. [15] using platinum (II) acetylacetonate ($Pt(C_5H_7O_2)_2$, 99.99%, Aldrich), cobalt naphthenate ($CoC_{22}H_{14}O_4$, 6 wt% in mineral spirits, Aldrich), and titanium (IV) butoxide ($Ti(OCH_2CH_2CH_2CH_3)_4$, 97%, Aldrich) as Pt, Co, and

TiO₂ precursors, respectively. The catalysts prepared by FSP are denoted as (F) Pt/TiO₂ and (F) Pt-Co/TiO₂, respectively. The TiO₂ supported Pt and PtCo catalysts were also prepared by incipient wetness impregnation using platinum (II) acetylacetonate $(Pt(C_5H_7O_2)_2, 99.99\%, Aldrich)$, cobalt naphthenate $(CoC_{22}H_{14}O_4, 6 \text{ wt}\%)$ in mineral spirits, Aldrich) as Pt and Co precursors and P-25 TiO₂ as the support. The catalysts were dried in an oven at 100°C overnight, and calcined in air at 500°C for 2 h. The impregnated catalysts are denoted as (I) Pt/TiO₂ and (I) Pt-Co/TiO₂, respectively.

2.2 Catalyst characterization

The XRD patterns were recorded using a Bruker D8 Advance X cay diffractometer with Ni-filter CuK_a radiation. The actual amount of Pt and Co loadings in the samples were analyzed by AS. The N₂ physisorption was conducted by using a Micrometrics ASAP 2020 instrument with the Brunauer–Emmett–Tc.lc.r (BET) method. The TEM observations were performed with a JEOL JEM 2010 transmission electron microscope operated at 200kV and equipped with LaB₆ thermoionic electron-gun, an UHR pole piece (point resolution 0.196 nm) and a P, nt; fet Link-INCA EDX spectrometer (Oxford Instruments). The percentages of Pt dispersion were measured by CO pulse chemiser; dion using a Micromeritics ChemiSorb 2750 equipped with ChemiSoft TPx software. Prior to chemisorption, the catalyst was reduced with hydrogen (25 cm³/min) at 500 °C for 2 h and then cooled down to the room temperature under helium flow (25 cm³/min). The H₂-TPR was carried out on a Micromeritics ChemiSorb 2750 with ChemiSoft TPx software. The sample was pretreated at 150 °C under N₂ flow (25 cm³/min) for 1 h. The FT-IR spectra of adsorbed CO were collected using

FTIR-620 spectrometer (JASCO) with a MCT detector at a wavenumber resolution of 2 cm⁻¹. The sample was heated to 300°C and reduced by H_2 for 30 min.

2.3 Catalytic reaction study

Prior to the reaction test, the catalyst was reduced with hydrogen (25 cm³/min) at : 00 °C for 2 h. Approximately 0.05 g of catalyst was dispersed into the reactant mixture of 50 μ L furfural (99%, Aldrich) a. d 10.0 mL methanol (98%, Aldrich) in 100 cm³ stainless steel autoclave reactor (JASCO, Tokyo, Japan). The selective hydrogen ation reaction was carried out at temperature of 50 °C and H₂ pressure of 2 MPa for 2 h. After that, the liquid product was called and analyzed by a gas chromatography equipped with a flame ionization detector (FID) and Rtx-5 capillary column.

3. Results and discussion

Based on the XRD patterns o. th \circ P /TiO₂ and Pt-Co/TiO₂ catalysts (**Fig.1**), the crystalline phases of TiO₂ consisting of anatase phase at 20=25° (major), 37°, 48°, 55°, 56°, 62°, 71°, and 75° and rutile phase at 20 = 28° (major), 36°, 42°, and 57° [16] were observed. The characteristic peaks for Pt metal/Pt oxides and Co metal/Co oxides could not be detected due probably to the low amount of metal (Pt and Co) loading and/or high dispersion of these metals on the TiO₂ support. As shown in **Table 1**, the TiO₂ anatase phase composition of (I) Pt/TiO₂ (85.8%) was slightly lower than that of (F) PT/TiO₂ (89.6%). Adding Co by different methods led to different effects on the TiO₂ phase composition. When Co was co-impregnated with 0.7 wt% Pt on the TiO₂ support,

the anatase phase composition increased from 85.8 to 90.5% with increasing Co loading from 0.04 to 0.2 wt%. Because the ionic radius of Co^{2+} (0.075 nm) is not much different from Ti⁴⁺ (0.061 nm), it has been postulated that Co^{2+} ions could enter into TiO₂ anatase structure and inhibit the phase transformation from anatase to rutile [17]. Upon substitutional dopants, the level of oxygen vacancies decreased, inhibiting the rutile phase transformation [18, 19]. On the contrary, the TiO₂ anatase phase composition of the FSP-derived bimetallic Pt-Co catalysts was significantly decreased to ~70% comparing to i_{10} n onometallic (F) PT/TiO₂. The ionic substitution of Ti⁴⁺ with metal cationic ions could occur during the particle formation step during FSP. The replacement of Ti⁴⁺ with metal cationic ions having lower valences such as Co^{2+} would generate more of vg in vacancies, promoting phase transformation from anatase to rutile along the flame. Simultaneous formation of TiO₂ support to a d Co metal by using polymeric precursor [20] or by solgel technique [21] also showed similar effect of TiO₂ phase transformation as in the FSP method. The average crystallite size of anatase phase TiO₂ for the (F) PT/TiO₂ remained unalter to at 12 nm upon Co loading by FSP method whereas those obtained by co-impregnation led to a slight increase of anatase 1 has TiO₂ crystallite size from 12 to 16 nm.

The BET surface areas of th P'-ba equivalent catalysts prepared by impregnation were in the range of 52 - 60 m²/g, and were slightly larger than those prepared by FSP (43 50 m²/g). Regardless of the preparation method used, Co addition as a second metal led to the increment of the BET surface area. For a similar amount of metal loading, Pt dispersion of the Pt-based catalysts prepared by impregnation was higher than that prepared by FSP. During FSP synthesis, suppression of CO chemisorption on surface Pt sites may be due to partial coverage of metal surface by the support matrix [22, 23]. However, addition of Co as a second metal resulted in

higher Pt dispersion regardless of the preparation method used. The interaction between Pt and Co was reported to compensate the electron deficiency of Pt sites by d-electron rehybridization, thus enhancing the adsorption ability of CO [24].

The H₂-TPR profiles of the catalysts are shown in Fig. 2. All the synthesized Pt-based catalysts showed three major reduction peaks at 94 - 105°C, 313 - 380°C, and 509 - 687°C, which were attributed to the reduction of PtO_x particles to metallic Pt⁰ particles, the reduction of Pt species interacting with the TiO₂ support in the form of Pt-TiO_x interface rius, and the reduction of surface capping oxygen of TiO₂ support, respectively [25]. It is obviously seen that the reduction beak of the Pt-TiO_x interface sites for the (F) Pt/TiO₂ catalyst shifted towards higher temperature and became broader comp. red to the (I) Pt/TiO₂, indicating the stronger metalsupport interaction induced by FSP method. For both cases, Co addit on as a second metal in the Pt-based catalysts further shifted the reduction temperature of the Pt-TiO_x species, due probably to the Pt-Co interaction and/or the migration of Co particles onto the Pt surface (decoration effect) [26]. Moreover, the reduction of surface capping oxygen of TiO₂ drastically shifted from 545°C for the monometallic (I) Pt/TiO₂ to 615 - 687°C for the bim tallic (I) Pt-Co/TiO₂ while those of the FSP made catalysts remained unchanged at 510°C. On the other hand, for bir. etc lic ^ot-co/TiO₂, the Pt-TiO_x reduction peak of (I) Pt-Co/TiO₂ were located at higher temperatures compared to (F) Pt-Co.T. J₂, which could be attributed to stronger metal-support interaction upon Co addition on the impregnated catalysts. As a consequence, the (I) Pt-0.2Co/TiO₂ showed higher conversion and selectivity of FA compared to (F) Pt-0.2Co/TiO₂, which was consistent with the metal-support interaction from H₂-TPR. Nevertheless, it can be suggested that Co addition on FSP-made catalyst was not necessary for improvement of the interaction between metals and support in order to enhance the selectivity to FA.

As observed from the TEM images (**Fig. 3**), the monometallic (I) Pt/TiO_2 catalyst was significantly composed of very small and narrowly distributed nanoparticles (≤ 2 nm). Very rarely large (10 – 100 nm) Pt particles could be observed. (F) Pt/TiO_2 catalyst showed three types of nanoparticle sizes. First, a collection of very small nanoparticle (≤ 2 nm) similar to the one found on (I) Pt/TiO_2 , then a collection of nanoparticles between 3 and 10 nm, and finally some very large spherical nanoparticles with sizes of several tens to several hundreds nm. It is suggested that (I) Pt/TiO_2 essentially showed very small Pt nome particle sizes (≤ 2 nm) and the selectivity of FA was significant lower than the (F) Pt/TiO_2 . The selectivity of FA may dependent of the Pt particle size. It has been report that Pt nanoparticles of sizes less than 2 nm supported on the silica are highly selective to ward decarbonylation of furfural to main product of furan over vapor phase furfural hydrogenation [6].

Concerning the Co addition as a second metal, (I) ^Dt-0.2. ^o/TiO₂ was essentially consisted of very small nanoparticles as (I) Pt/TiO₂. The average particle size of these nanoparticles at the physical increased with the addition of Co (1.7 nm for (I) Pt-0.2Co/TiO₂ and 1.3 nm for (I) Pt/TiO₂) and the particle size distribution was substantially broader. There are also very rare of larger particles. The (F) Pt-0.2Co/TiO₂ catalyst also showed the race ensuits similar to those of (F) Pt/TiO₂. Two types of nanoparticles and some large spherical ones. The smaller nanoparticles also slightly increase in size of 1.9 nm for (F) Pt-0.2Co/TiO₂ compared to 1.5 nm for (F) Pt/TiO₂. The intermediate nanoparticles were not vary too much in size (6.8 nm for (F) Pt-0.2Co/TiO₂ compared to 6.2 nm for (F) Pt/TiO₂). The large spherical particles have several hundreds nm. The larger spherical particles that originated by FSP method were much larger than the size of the grains of titania and thus their interaction was poor, resulting to reduce the catalytic activity. The IR spectra of adsorbed CO on the different catalysts reduced at 500°C are shown in **Fig. 4**. The bands at 2188 - 2185 cm⁻¹ represented to

CO formed with Ti^{4+} cations on the surface [27]. The band at 2086 - 2078 cm⁻¹ was assigned to CO linearly adsorbed on low coordination Pt (Pt⁰-CO) or Co (Co⁰-CO) atoms on edge sites, while the band at 1850 cm⁻¹ was assigned to CO bridged between two Pt metal atoms (Pt⁰-CO-Pt⁰). It has been reported that linear-type adsorbed CO dominated on small Pt particles while bridge-type adsorbed CO formed mainly on larger Pt particles [28, 29]. The ratio of Pt on linearly CO adsorbed (Pt⁰-CO) to bridged CO adsorbed (Pt⁰-CO-Pt⁰) atom was high due to the presence of very small Pt particles size (≤ 2 nm), which was consistent with the average particle size observed from TEM and further increase selectivity of FA with the Co addition. The Pt⁰-CO band center of (F) Pt/TiO₂ shifted to lower frequency with lower intensity compared to (I) Pt/TiO₂. The lower shift and increase in intensity of the Pt⁰-CO band were also observed in bimetallic (F) Pt-0.2Co/TiO₂ compared to (I) Pt-0.2Co/T₁O₂

3.2 Catalytic reaction study

In this study, FA was the only desired or vduct being formed and 2-furaldehyde dimethyl acetal was the solvent product (SP) which can be generated upon furfur 1 a eta'ization when using methanol as the solvent [3] in the presence of metal catalysts. The catalytic performances of all the Pt-bar ed catalysts in the liquid-phase selective hydrogenation of furfural to FA are summarized in **Table 2**. The furfural conversion and selectivity to FA over (I) Pt/TiO₂ catalyst were 84.6% and 71.5%, respectively. Modification of (I) Pt/TiO₂ by Co addition, furfural conversion and selectivity to FA increased with increasing Co loading up to 0.2 wt% in which furfural was fully converted within 2 h of reaction time and high selectivity to FA up to 97.5% was achieved. Improvement in furfural conversion upon Co addition by co-impregnation was correlated with high Pt dispersion and high TiO₂ anatase phase composition.

The subsurface oxygen vacancies on the reduced anatase TiO_2 -supported metal catalysts were found to be favorable adsorption sites for H atoms [30]. On the other hand, the hydrogen would weakly interact with the rutile TiO_2 -supported ones [31]. In addition, increase in the selectivity to FA could be attributed to the formation of Pt-TiO_x interface sites, in which oxygen atom in the C=O group of furfural could be coordinated via a lone pair of electrons, promoting the selective activation of carbonyl bonds in furfural [32]. In the perspective of electronic effect, the stronger interaction between Pt and $TiO_2 s_{aP_1}v_0$, indicated more electron transfer from support to metals, thus leading to the formation of electron-rich metal particles. The electronegativity of metal catalysts has been reported to affect the C=O activation in furfural hydrogenation [32]. Stronger electronegativity of metal particles (or electron-rich metals) could activate the C=O bond towards the furfural hydrogenation to z^2A . Similar results have been reported over Cu/TiO₂-SiO₂, Au/Al₂O₃, Fe-promoted Ni-B amorphous alloy catalyst, Au/ZrC₂, and Au/TiO₂.

Furfural conversion of the monometallic (F) Pt F_{C_2} was not much different from the (I) Pt/TiO₂ catalyst but the selectivity to FA was found to be largely improved. This involvement was attributed to the stronger metal-support interaction upon FSP. However, Co addition upon FSP slightly improved the selectivity to FA but decreased furfural conversion. It is suggested that the presence of higher rutile TiO₂ phase diminish the furfural conversion despite its high Pt dispersion based on CO chemisorption ability. Nevertheless, it could be said that Co addition into the Pt-based catalysts upon FSP was unnecessary for modification of the interaction between metals and support in order to enhance the selectivity to FA. Comparing the bimetallic Pt-0.2Co/TiO₂ catalysts prepared by impregnation and flame spray pyrolysis, the (I) Pt-0.2Co/TiO₂ catalyst showed higher furfural conversion and selectivity to FA than the (F) Pt-0.2Co/TiO₂ catalyst because of higher Pt dispersion, TiO₂ anatase phase composition, and the strong interaction

between metals and support. Among all Pt-based catalysts in this study, the (I) Pt-0.2Co/TiO₂ exhibited the highest FA yield at 97.5%. The activity of 1st cycle and 2nd cycle for (F) Pt-0.2Co/TiO₂ catalyst were 71.1% and 67.4%, respectively. It can be observed that the activity decreased by 5.2% after 2nd reaction. **Table 3** shows a comparison between the Pt-based catalysts in this study and those reported in the literature. It is notable that one of the best results with furfural conversion (100%) and FA selectivity (95.7%) could be obtained over 2 wt% Pt-1 wt% Re/TiO₂-ZrO₂ [10], however more severe conditions (130°C, 5 1 (Pa of H₂)) and long reaction time (8 h) were used in the presence of ethanol as a solvent. The catalysts in the present structure similar conversion/selectivity under milder reaction conditions.

4. Conclusions

While Co addition via co-impregnation on $Pt/T_{1}C_{2}$ analysts improved both furfural conversion and selectivity to FA due to higher TiO₂ anatase phase composition, high Pt visporsion, and stronger interaction between metals and support, formation of Pt-Co/TiO₂ by one-step FSP resulted i. a tect based furfural conversion despite its high Pt dispersion due to the acceleration of rutile phase transformation of the TiO₂. How ever, a largely improvement of FA selectivity on the FSP-made catalysts was attributed to the stronger metal-support interaction upon FSP as revealed by the higher reduction temperature of the Pt-TiO_x interface sites. Thus, modification of the Pt/TiO₂ by Co addition was unnecessary for catalyst improvement when using the FSP Pt/TiO₂ catalysts.

Acknowledgments

The financial supports from the Rachadapisek Sompote Endowment Fund for the Postdoctoral Fellowship, Chulalongkorn University for W.T. and the Thailand Science Research and Innovation for the Basic Research grant BRG6180001, IRN62W0001, and CAT-REAC Industrial Project RDG6250033 are gratefully acknowledged. The authors also would like to thank the Research Team Promotion grant from the National Research Council of Thailand (NRCT).

Declaration of interests

The authors declare that they have no known competing financial internst or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personel relationships which may be considered as potential competing interests:

Credit Author Statement

Weerachon Tolek: Conducting a recearch and investigation process, specifically performing the experiments, or data/evidence collection, Writing first draft

Kitima Khruechao: Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection

Boontida Pongthawornsakun: Data analyzing and discussion

Okorn Mekasuwandumrong: Data analyzing and discussion

Francisco José Cadete Santos Aires: Data analyzing and discussion

Patcharaporn Weerachawanasak: Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection

Joongjai Panpranot: Acquisition of the financial support for the project leading to this publication, Reviewing and Editing

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Table 1. Metal loading, XRD analysis, N₂ physisorption properties and Pt dispersion results of the Pt-based catalysts.

	Metal lo	adings ^a	Crystallite	Phase composition ^b		N ₂ physicol ption results			
Catalyst	Pt (wt.%)	Co (wt.%)	size of anatase TiO_2^{b} (nm)	Anatase (%)	Rutile (%,)	LF7 surface areas (m ² /g)	Average pore diameter ^c (nm)	Pore volume ^c (cm ³ /g)	Pt dispersion ^d (%)
(I) Pt/TiO ₂	0.73	-	12	85 8	14.2	52.2	16.5	0.28	23.4
(I) Pt-0.04Co/TiO ₂	0.70	0.04	14	85.1	11.9	59.3	18.7	0.34	26.8
(I) Pt-0.1Co/TiO ₂	0.67	0.11	14	89.7	10.3	59.5	18.8	0.35	32.2
(I) Pt-0.2Co/TiO ₂	0.66	0.22	16	90.5	9.5	60.0	25.1	0.44	35.0
(F) Pt/TiO ₂	0.66	-	12	89.6	10.4	42.6	14.0	0.12	19.2
(F) Pt-0.2Co/TiO ₂	0.65	0.20	12	82.4	17.6	44.5	10.7	0.11	20.1
(F) Pt-0.4Co/TiO ₂	0.74	0.48	12	69.0	31.0	49.8	10.6	0.10	42.4

^a Determined by atomic absorption spectroscopy

^b Base on XRD results

^c Determined from the Barret-Joyner-Halenda (BJH) desorption method

^d Based on CO-chemisorption

Catalvet	Conversion (%)	Selectivity (%)			
Cataryst	Conversion (70)	Furfuryl alcohol	Solvent product		
(I) Pt/TiO ₂	84.6	71.5	28.5		
(I) Pt-0.04Co/TiO ₂	85.8	88.9	11.1		
(I) Pt-0.1Co/TiO ₂	86.4	93.5	6.5		
(I) Pt-0.2Co/TiO ₂	100	97.5	2.5		
(F) Pt/TiO ₂	83.4	95.1	4.9		
(F) Pt-0.2Co/TiO ₂	71.1	95.5	4.5		
(F) Pt-0.4Co/TiO ₂	68.3	97.2	2.8		

Table 2. Catalytic performances for all Pt-based catalysts in the liquid-phase selective hydrogenation of furfural to furfuryl alcohol under mild reaction conditions.

Reaction: 50 μ L furfural in 10 ml methanol at 50 °C with 50 mg catalyst unde. 20 Jar H₂ for 120 min Solvent product: 2-furaldehyde dimethyl acetal

				Results			
No.	Catalysts	Reaction conditions	Reaction in e (h)	Conversion (%)	FA selectivity (%)	Ref.	
1	(I) Pt-0.2Co/TiO ₂	50°C, 2 MPr of H ₂	2	100	97.5	This work	
2	Pt-Re/TiO ₂ -ZrO ₂	130°C, 5 N P [,] . ^f H ₂	8	100	95.7	[10]	
3	Pt/y-Al ₂ O ₃ Pt/MgO Pt/CeO ₂	50°C, əmbient of H_2	7	80 79 77	99 97 98	[3]	
4	Cu-Pt/SiO ₂ Pt/SiO ₂	25J°C, 0.7 MPa of H ₂	1.5	15.3 12.5	90.5 55.8	[9]	
5	Pt/Al ₂ O ₃	25°C, 6 MPa of H ₂	1	65.6	99.7	[1]	
6	Pt/SiO ₂	100°C, 2 MPa of H ₂	5	31	29	[2]	

Table 3. Comparison between the synthesized Pt-based cotalysts in this work and others

Fig. 1. XRD patterns of the Pt-based catalysts prepared by impregnation and flame spray pyrolysis.

Fig. 2. H₂-TPR profiles of (a) (I) Pt/TiO₂, (b) (I) Pt-0.04Co/TiO₂, (c) (I) Pt-0.1Co/TiO₂, (d) (I)

Pt-0.2Co/TiO₂, (e) (F) Pt/TiO₂, (f) (F) Pt-0.2Co/TiO₂ and (e) Pt-0.4Co/TiO₂ catalysts.

Fig. 3. TEM micrographs and particle size distribution of (a) (I) Pt/TiO₂, (b) (I) Pt-0.2Co/TiO₂,

(c) (F) Pt/TiO_2 and (d) (F) $Pt-0.2Co/TiO_2$ catalysts.

Fig. 4. IR spectra of CO adsorbed on (a) (I) Pt/TiO₂, (b) (I) Pt-0.2Co/TiO₂, (c) (F) Pt/TiO₂ and

(d) (F) Pt-0.2Co/TiO₂ catalysts.

Graphical abstract

Highlights

- Flame spray-synthesized Pt/TiO_2 and $PtCo/TiO_2$ with 0.7 wt% Pt and \therefore -0.4 wt% Co
- Appropriate uniform Pt particle size 3.1-3.5 nm with strong Pt-TiC , interface sites
- High furfuryl alcohol selectivity (> 95%) with and without Co addition
- Co adding during FSP accelerated rutile TiO₂, leading to low catalys: activity
- Opposite trend observed on co-impregnated PtCo, performance improved by adding Co

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