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Elucidating the effect of solid base on the hydrogenation of C5 and C6 sugars over Pt–Sn bimetallic catalyst at room temperature

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conditions

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<i>Keywords:</i> Sugar Sugar alcohols Bimetallic catalyst Hydrogenation Hydrotalcites	Conversion of sugars into sugar alcohols at room temperature with exceedingly high yields are achieved over $Pt-Sn/\gamma-Al_2O_3$ catalyst in the presence of calcined hydrotalcite. pH of the reaction mixture significantly affects the conversion and selectivity for sugar alcohols. Selection of a suitable base is the key to achieve optimum yields. Various solid bases in combination with $Pt-Sn/\gamma-Al_2O_3$ catalysts were evaluated for hydrogenation of sugars. Amongst all combinations, the mixture $(1:1 wt/wt)$ of $Pt-Sn/\gamma-Al_2O_3$ and calcined hydrotalcite showed the best results. Hydrotalcite helps to make the pH of reaction mixture alkaline at which sugar molecules undergo ring opening. The sugar molecule in open chain form has carbonyl group which can be polarized by Sn in $Pt-Sn/\gamma-Al_2O_3$ and Pt facilitates the hydrogenation. In the current work, effect of both; solid base and Sn as a promoter has been studied to improve the yields of sugar alcohols from various C5 and C6 sugars at very mild reaction

1. Introduction

Environmental concern and exhausting fossil carbon sources caused paradigm shift towards the processing of biomass for the production of fuels and chemicals in the recent decades. Development of efficient catalysts and processes is the need of time to meet the requirement in a sustainable and economical way. Lignocellulosic biomass can serve as renewable source for chemicals and fuels. It consists of cellulose, hemicellulose and lignin in various amounts depend on its origin. Cellulose is homo-polysaccharide made up of glucose while hemicelluloses are hetero-polysaccharide made up of various C5 and C6-sugars depending upon its origin. Lignin is highly branched polymer of aromatic compounds. Conversion of cellulose and hemicellulose into sugars and further conversion of sugars to furans, sugar alcohols, glycols, etc. is well known [1–8]. Sugar alcohols are considered as important biomass derived compounds because of its wide spread applications in various fields like, oral hygiene products, pharmaceutical industry, in cosmetics, for production of various chemicals and H₂ generation, therefore its demand is escalating continuously [9-16]. Conventionally sugar alcohols such as sorbitol and xylitol are prepared over supported metal catalysts and nickel-based catalysts are used more extensively [9,10,

17–21]. Many other catalysts including noble metal-based catalysts also have been explored for the conversion of sugars to sugar alcohols [22–35]. But these catalysts have some obvious drawbacks like catalyst deactivation, requisite of harsh reaction condition or low yields of sugar alcohols [36-38]. In current work, the conversion of C5-sugars (xylose, arabinose) and C6-sugars (glucose, galactose) into respective sugar alcohols at room temperature is studied over Sn promoted Pt/y-Al₂O₃ catalyst in presence of solid base (Scheme 1). Sn is known to promote the activity of Pt/y-Al2O3 catalyst toward the hydrogenation reaction [39–41]. Recently hydrogenation of xylose to xylitol at milder reaction condition (130 °C, 16 bar H₂) over Pt–Sn/ γ -Al₂O₃ is reported with high yield (93%) [6]. In yet another report, increment in the yield of sugar alcohols from sugars, polysaccharide (xylan, arabinogalactan, inulin) and agricultural wastes was achieved over Pt-Sn/y-Al2O3 [42]. Similarly, the effect of solid base (C-HT) in the conversion of sugars to sugar alcohols over Pt/y-Al2O3 catalyst is studied and high yield of sugar alcohols (82% xylitol from xylose) was achieved [5].

In the view of this, it is interesting to explore the effect of hydrotalcite in the conversion of sugars over Pt–Sn/ γ -Al₂O₃ bimetallic catalyst. The combined effect of Sn and hydrotalcite is anticipated to enhance the hydrogenation activity of Pt/ γ -Al₂O₃. Although, the effect

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Scheme 1. Conversion of sugars to sugar alcohols at room temperature.

of base in ring opening of sugars and its role in keto-enol tautomerization (known as Lobry de Bruyn-Albeda van Ekenstein transformation) is well known, the systematic studies correlating the activity with pH/ basicity are missing. There is enough scope to establish a relation between catalytic activity and pH of the reaction mixture. Therefore, in present work solid bases with various basicity were used in combination with the catalyst, which results into varying pH of the reaction mixtures. Effect of pH of the reaction mixture on the yield and selectivity is studied in systematic way. Moreover, solid bases were used for the study to maintain heterogeneity of the catalytic systems.

2. Experimental

2.1. Materials

 γ -Al₂O₃ (AL), sorbitol (99.9%), hydroxyapatite (99.9%), calcium oxide (99.9%) and magnesium oxide (98%) were purchased from Aldrich Chemicals, USA. Glucose (99%), galactose (98%), galactitol (99%), mannitol (99.5%), xylitol (99%), arabitol (99%), glycerol (98%), ethylene glycol (99%), 1,2-propanediol (99.5%), were procured from s. d. fine chemicals, India. Tetraamine platinum nitrate (99.9%) was obtained from Alfa Aesar, UK. Stannus chloride dihydrate (98%), xylose (99%), arabinose (99%) and sodium hydroxide (98%), Sodium corbonate (99.9%) were purchased from Loba Chemicals, India. Magnesium nitrate hexahydrate (99%) was purchased from Merk, India. Aluminum nitrate nonahydrate (99%) was procured from Thomas Baker, Germany.

2.2. Synthesis of hydrotalcite

Mg–Al hydrotalcite was prepared by co-precipitation method with Mg/Al ratio 3. Na_2CO_3 was used as a source of carbonate and NaOH was used to maintain the pH of the solution. 37.5 mL aqueous solution of Mg $(NO_3)_2$ ·6H₂O (0.279 mol) and Al $(NO_3)_3$ ·9H₂O (0.093 mol) was added drop wise into the 37.5 mL aqueous solution of NaOH (0.4375 mol) and Na_2CO_3 (0.1125 mol) under stirring. During addition pH of the solution was maintained between 8 and 10. The white precipitate obtained was kept for digestion in autoclave for 16 h at 60 °C. The slurry was filtered

and powder was washed with deionized water till pH becomes neutral. The white powder thus obtained was dried at 80 °C for 16 h followed by calcinations at 550 °C for 8 h in the flow of air (20 mL/min). Calcined hydrotalcite was used as a support material to prepare catalyst or added as a solid base along with catalyst.

2.3. Catalyst preparation

Supported metal catalysts were prepared by co-impregnation method using γ-Al₂O₃ (AL) or calcined hydrotalcite (C-HT) supports. Prior to catalyst preparation, supports were evacuated at 150 °C for 6 h under vacuum (-700 Torr). Mixture of the support and water (1 gm support in 10 mL water) was stirred for 1 h at room temperature. Required amount of metal precursor solution was added drop wise to the support suspension under stirring (10 wt% aqueous solution of Pt (NH₃)₄(NO₃)₂ and 10 wt% solution of SnCl₂·2H₂O in 3 M HCl). The mixture was stirred for 16 h at room temperature (30 \pm 3 °C), after this solvent was removed by rotary vacuum evaporator. Powder was dried at 60 °C overnight in oven and at 150 °C for 3 h under vacuum. Dried powder was calcined at 400 °C for 2 h in a flow of oxygen (20 mL/min) and reduced in a hydrogen flow (20 mL/min) at 400 °C for 2 h. Pt/AL. Pt–Sn/AL, Pt/C-HT and Pt–Sn/C-HT catalysts were prepared by keeping Pt loading of 2 wt% and Sn loading of 0.25 wt% i.e. Pt(2)/AL (2 wt%Pt/ γ-Al₂O₃), Pt(2)Sn(0.25)/AL (2 wt%Pt-0.25 wt%Sn/γ-Al₂O₃), Pt(2)/C-HT (2 wt%Pt/C-HT) and Pt(2)Sn(0.25)/C-HT (2 wt%Pt-0.25 wt%Sn/C-HT).

2.4. Catalyst characterization

Characterization of the catalysts was performed using various techniques. Dona Quantachrome Nova 4200e instrument was used for the nitrogen sorption study and TPD was performed using Micrometrics Autochem-2910. Inductively coupled plasma atomic emission spectroscopy (ICP-AES) was performed using SPECTRO ARCOS Germany, FHS12 instrument. The X-ray diffraction patters of the catalysts were recorded using Philips Powder XRD machine, operated at Cu K α radiation ($\lambda = 1.540598$ Å). Transmission electron microscopy (TEM) was done using FEI Tecnai TF-30 instrument. X-Ray photoelectron spectroscopy (XPS) study was performed using VG Micro Tech ESCA-3000 instrument (operating under ultrahigh vacuum).

2.5. Catalytic test

Reactions were conducted in a batch mode autoclave of 50 mL capacity (Amar Equipments, India). Substrate/catalyst ratio was kept constant as 2 wt/wt i.e. 0.15 g substrate and 0.075 g catalyst were taken in 35 mL of water. 0.075 g of C-HT was added wherever effect of solid base was studied. After adding water, substrate and catalyst, H₂ was charged into the reactor with required pressure (16 or 24 bar at room temperature). Experiments were carried out in a temperature range of room temperature (32 \pm 3) to 80 °C, for various reaction times. Reaction mixture was stirred at 150 rpm until desired temperature is reached then stirring was increased to 900 rpm and this was considered as starting time of the reaction. For room temperature experiments, reaction mixture was stirred at 900 rpm since beginning. After reaction, autoclave was cooled down to room temperature under the flow of air. The catalyst was separated from reaction mixture by centrifugation and the liquid was filtered through 0.22 µm syringe filter. The products were analyzed using HPLC (Agilent Technologies, 1200 infinity series, USA) equipped with HC-75 Pb⁺⁺ (Hamilton, 7.8 mm \times 300 mm) column maintained at 80 $^\circ\text{C}.$ Deionized water (flow rate 0.6 mL) was used as an eluent. Refractive index detector (RID, Agilent Technologies, 1200 infinity series, cell temperature, 40 °C) was used for the detection of compounds. Another HPLC system (Agilent Technologies, 1200 infinity series, USA) equipped with HC-75H⁺ (Phenomenex, 7.8 \times 300 mm) column (at 60 $^\circ\text{C})$ with sulfuric acid (0.5 mmol) as an eluent (0.6 mL/ min flow rate) was also used to quantify the products. RID (Agilent Technologies, 1200 infinity series, cell temperature, 40 °C) was used for detection of compounds.

3. Results and discussion

3.1. Catalyst characterizations

All synthesized catalysts were characterized using various techniques i.e. ICP-AES, N2 sorption, TPD, XRD, TEM, XPS, etc. Results obtained from various characterizations are summarized in Table 1. The surface area for AL determined by N2 sorption technique was found to be 174 m^2/g , while after metal impregnation it was slightly decreased (Table 1 entry 1,2,3). Similarly, the surface area of C-HT was decreased after metal impregnation (Table 1, entry 4,5,6). The acid and base amounts of the samples were determined by NH₃-TPD and CO₂-TPD respectively. NH₃-TPD profiles for AL, Pt(2)/AL and Pt(2)Sn(0.25)/AL are shown in Figs. S1-A (†ESI). The profile for AL showed a broad peak nearly at 200 °C indicating presence of weak acid sites. The decrease in total acidity of AL after metal impregnation is pointing towards the interaction of metals with acid sites. In the profile of Pt(2)Sn(0.25)/AL small hump at 400-500 °C was observed which was not observed for AL and Pt(2)/AL indicates the acid sites arose due to Sn with positive charge. It is well known fact that Sn forms tin-aluminate on the surface of AL, therefore complete amount of Sn can't be reduced to Sn (0) if supported on AL [43-45]. The Sn species with positive charge can generate new type of acid sites and the peak observed at 400-500 °C in this study might be due such acid sites (Table 1, entry 1,2,3). The CO2-TPD profiles for C-HT, Pt(2)/C-HT and Pt(2)Sn(0.25)/C-HT are shown in Figs. S1-B (†ESI). The slight decrease in the base amount of C-HT was observed after impregnation of metals (Table 1. Entry 4,5,6). The metal contents of the samples were determined using ICP-AES. Expected metal loadings and actual metal loadings determined by ICP-AES are very much similar (Table 1).

XRD patterns for various catalysts are shown in Fig. S2 (†ESI). Both Pt(2)/AL and Pt(2)Sn(0.25)/AL catalysts showed sharp peaks for Pt (Joint Committee on Powder Diffraction Standards, JCPDS file no. 01-088- 2343). From XRD pattern of Pt(2)Sn(0.25)/AL it can be concluded that no alloy or inter metallic species was formed in bulk quantity (concentration must be very less, hence not detected by XRD). Because of high dispersion of Pt, peak intensity was lower in Pt(2)Sn (0.25)/AL than in Pt(2)/AL. In Pt(2)/C-HT and Pt(2)Sn(0.25)/C-HT peak intensity for Pt was very low because of highly dispersed Pt on C-HT support compare to AL support (Fig. S2, †ESI). TEM analysis showed that the particle size of Pt in Pt(2)/AL and Pt(2)Sn(0.25)/AL was 20-30 nm and 10-20 nm respectively (Fig. 1). Better dispersion in Pt(2) Sn(0.25)/AL catalyst compare to Pt(2)/AL catalyst, is because of interaction of Sn with support (AL). Sn interacts with alumina to form tinaluminate type structure [43]. Hence, Sn forms surface shell with alumina which prevents mobility of Pt particle during calcinations and reduction [43,44]. In case of C-HT based catalyst, in both Pt(2)/C-HT and Pt(2)Sn(0.25)/C-HT particle size was 2-3 nm (Fig. 1). This shows

the better support metal interaction of the metals with C-HT than that with AL. The oxidation state of Sn was determined by XPS study. On γ -Al₂O₃ support, Sn cannot be reduced to (0) oxidation state even when reduced at 500 °C [45]. In this study, catalysts were reduced at 400 °C so Sn may present in (II) or (IV) oxidation state. XPS spectra showed peak at 486.5 eV which is characteristic for Sn (II) or (IV) (Fig. S3, †ESI). It is difficult to distinguish between Sn (II) and (IV) by XPS as the difference in binding energy is very low [6].

3.2. Hydrogenation of C5-Sugars

Hydrogenation reactions of xylose were carried out at room temperature under 24 bar H2 pressure to evaluate the catalytic activity of various catalysts (Table 2). Conversion of xylose was only 20% after 28 h over monometallic Pt(2)/AL catalyst and 18% yield of sugar alcohols (xvlitol + arabitol) was obtained. The conversion was doubled (40%) and 38.5% yield of sugar alcohols was obtained when bimetallic Pt(2)Sn (0.25)/AL was used. Further improvement in the conversion and yield was observed when Pt(2)/C-HT and Pt(2)Sn(0.25)/C-HT catalysts were employed at similar reaction condition. Highest yield of sugar alcohols (96%) was obtained with almost complete conversion (97%) over (Pt(2) Sn(0.25)/AL + C-HT catalytic system i.e. the physical mixture of Pt(2)Sn (0.25)/AL and C-HT. Other than sugar alcohols, side products like glycols (glycerol + ethylene glycol + 1,2-propanediol) were formed but in negligible quantity.

To check the possibility of conducting reactions at lower pressure, reaction of xylose over Pt(2)Sn(0.25)/AL + C-HT was conducted at 16 bar H₂ keeping other parameters same. But, the yield of sugar alcohols was observed to be decreased to 85% (87% conversion), indicating that 16 bar pressure is not enough to achieve complete conversion within 28 h at room temperature. Further, hydrogenation reactions of arabinose (another C5 sugar) were conducted at 24 bar pressure at room temperature for 28 h (Table 3). The catalytic activity of various catalysts towards the hydrogenation of arabinose follows the same trend as that for xylose hydrogenation. Maximum 97.5% yield of sugar alcohols (arabitol + xylitol) was achieved using Pt(2)Sn(0.25)/AL + C-HT catalytic system at room temperature. Highest yield of sugar alcohols was achieved over Pt(2)Sn(0.25)/AL + C-HT catalyst. This is because of the combined effect of Sn (in ionic form) and presence of C-HT. Ionic Sn helps to polarize the C=O bond in carbonyl group of sugars and hydrogenation of polarized C=O bond is easier [6]. C-HT is a solid base by addition of which pH of the reaction medium becomes alkaline (Approx. 9). As reported elsewhere, UV absorption study proves that more number of sugar molecules are present in open chain form in alkaline medium than that of in neutral medium [5]. In addition, at basic pH keto-enol tautomerization can occur which might result in isomerisation/epimerization of sugar (Fig. S4, †ESI). This is the reason for formation of sugar isomers and the respective alcohols in present study. For an instance; in xylose hydrogenation arabitol was observed along with xylitol while in glucose hydrogenation mannitol was observed along with sorbitol.

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Properties of catalysts.

Entry	Catalyst	Acidity ^a (mmol/g)	Basicity ^b (mmol/g)	Surface area ^c (m ² /g)	Pt content	Pt content (wt%) Sn content (wt%)		(wt%)
					Actual ^d	Expected	Actual ^d	Expected
1	AL	0.42	-	174	-	-	-	-
2	Pt(2)/AL	0.24	-	157	2.13	2.00	-	-
3	Pt(2)Sn(0.25)/AL	0.22	-	164	2.16	2.00	0.22	0.25
4	C-HT	-	0.87	210	-	-	-	-
5	Pt(2)/C-HT	_	0.78	148	2.19	2.00	-	-
6	Pt(2)Sn(0.25)/C-HT	-	0.61	134	2.17	2.00	0.21	0.25

^a Determined by NH₃-TPD.

^b Determined by CO₂-TPD.

^c Determined by N₂ sorption.

^d Determined by ICP-AES.





Fig. 1. TEM images of various catalysts.

Table 2	
Conversion of xylose over various catalysts at room temperature.	

Catalvet	Product vield (%)			Conv	TOF
Catalyst	Xylitol	Arabitol	Sugar alcohols	(%)	(h^{-1})
Pt(2)/AL Pt(2)Sn(0.25)/AL Pt(2)/C-HT Pt(2)Sn(0.25)/C- HT Pt(2)/AL + C.HT	17.0 36.0 77.0 80.0	1.0 2.5 3.5 4.0	18.0 38.5 80.5 84.0	20.0 40.0 85.0 89.0	12.2 15.5 8.3 8.7
Pt(2)Sn(0.25)/AL + C-HT	94.5	1.5	96.0	97.0	59.9

Reaction condition: xylose 0.15 g, catalyst 0.075 g, C-HT 0.075 g, H_2O 35 mL, 32 (±3) $^\circ C,$ H_2 24 bar at R.T., 28 h.

The effect of reaction temperature was studied by conducting the hydrogenation reaction of xylose at 50 °C at 24 bar H₂ pressure over Pt (2)Sn(0.25)/AL + C-HT catalyst. At this elevated temperature complete conversion of xylose was achieved within 6 h with 97% yield of sugar alcohols. When hydrogenation of xylose was conducted at 16 bar H₂ pressure instead of 24 bar over Pt(2)Sn(0.25)/AL + C-HT catalyst at 50 °C temperature (keeping other parameters same), no significant difference was observed in the yield of sugar alcohols. The results show

Table 3

Conversion of arabinose over various catalysts at room temperature.

Catalyst	Product yield (%)			Conv.	TOF
	Xylitol	Arabitol	Sugar alcohols	(%)	(h ⁻¹)
Pt(2)/AL	0.5	33.5	34.0	35.0	22.9
Pt(2)Sn(0.25)/AL	0.0	44.0	44.0	46.0	19.1
Pt(2)/C-HT	1.0	84.0	85.0	87.0	12.2
Pt(2)Sn(0.25)/C- HT	0.5	89.5	90.0	92.0	13.1
Pt(2)/AL + C-HT	1.0	92.0	93.0	95.0	110.4
Pt(2)Sn(0.25)/AL + C-HT	1.5	96.0	97.5	99.0	77.4

Reaction condition: arabinose 0.15 g, catalyst 0.075 g, C-HT 0.075 g, H_2O 35 mL, 32(±3) $^\circ C,$ H_2 24 bar at R.T., 28 h.

that at 50 °C of reaction temperature, 16 bar H₂ pressure and 6 h of reaction time is enough to achieve complete conversion. This is much obvious as the solubility of H₂ in water increases with temperature which facilitated the faster hydrogenation of xylose and complete conversion could be achieved in shorter reaction time. The results for hydrogenation of xylose over various catalysts at 50 °C and 16 bar pressure of H₂ are represented as Fig. 2. The highest yield of sugar alcohols (96%) was obtained over Pt(2)Sn(0.25)/AL + C-HT catalyst with complete



Fig. 2. Conversion of xylose over various catalysts. Reaction condition: xylose 0.15 g, catalyst 0.075 g, C-HT 0.075 g, H₂O 35 mL, 50 °C, H₂ 16 bar at R.T., 6 h.

conversion of xylose in 6 h.

It is very much clear from the above results that C-HT is plying significant role in hydrogenation of sugars. The possibility to recreate the similar effect using other solid bases was checked by using hydroxyapatite (HAP), magnesium oxide (MgO) and calcium oxide (CaO) instead of C-HT in combination with Pt(2)Sn(0.25)/AL catalyst for xylose hydrogenation (Fig. 3). Amongst all the catalytic systems, Pt(2)Sn(0.25)/AL + C-HT and Pt(2)Sn(0.25)/AL + MgO showed the highest yield for sugar alcohols. But MgO is soluble in water and hence difficult to reuse. The Pt(2)Sn(0.25)/AL catalyst without addition of any base showed 34% yield of sugar alcohols with 38% xylose conversion. When HAP was used along with Pt(2)Sn(0.25)/AL, 37% yield of sugar alcohols (40%



Fig. 3. Effect of various bases on xylose hydrogenation.

Reaction condition: xylose 0.15 g, catalyst (Pt(2)Sn(0.25)/AL) 0.075 g, base 0.075 g, H_2O 35 mL, 50 $^\circ C$ H_2 16 bar at R.T., 6 h.

conversion) was achieved while 96 and 98% yield (with complete xylose conversion) could be obtained using C-HT with Pt(2)Sn(0.25)/AL and MgO with Pt(2)Sn(0.25)/AL, respectively. Complete conversion was observed over CaO with Pt(2)Sn(0.25)/AL catalytic system but yield of sugar alcohols was only 64% due to the formation of side products like glycols. The activity can be correlated with pH of the reaction mixtures (after adding xylose, catalyst and base into water). The pH of reaction mixture in case of only Pt(2)Sn(0.25)/AL catalyst and Pt(2)Sn(0.25)/AL + HAP was 5.3 and 7.5 respectively, while in case of Pt(2)Sn(0.25)/AL + C-HT and Pt(2)Sn(0.25)/AL + MgO it was 9.2. and 9.4, respectively. In case of Pt(2)Sn(0.25)/AL + CaO the pH was 12.2. These results show that pH of the reaction medium has profound effect on the conversion and selectivity. pH in the range of 9-9.5 is the most suitable to achieve higher conversion of sugars and better selectivity for sugar alcohols. At lower pH the ring opening of sugar molecules could not occur up to significant extend at such a low temperature. This results into lower conversion of sugar (xylose) despite of having good hydrogenation catalyst (Pt(2)Sn(0.25)/AL). On the other hand, when pH of the reaction mixture was very high (as in the case of Pt(2)Sn(0.25)/AL + CaO), other side reactions like glycol formation by C-C bond breakage were more provoking. Therefore, mere addition of any base will not work but the selection of proper solid base with appropriate basicity is the key to improve conversion of sugar molecules without compromising the selectivity for sugar alcohols.

3.3. Hydrogenation of C6-Sugars

After achieving very high yield of sugar alcohols from C5 sugars (xylose and arabinose), catalyst Pt(2)Sn(0.25)/AL + C-HT was evaluated for the conversion of C6 sugars (glucose and galactose) at room temperature and 24 bar H₂. For complete conversion of glucose, the time required was 60 h and 84% yield of C6 sugar alcohols (sorbitol-76%+ mannitol-8%) was obtained. Galactose was converted completely at room temperature within 48 h to yield 87% galactitol and small amount of mannitol (3%). To check the effect of temperature in the conversion of glucose, reaction was conducted at 50 °C under 16 bar H₂. But only 43% conversion was observed with 36% yield of sugar alcohols in 6 h. When temperature was switch to 80 °C, complete conversion of glucose was achieved in 6 h to yield 88% sugar alcohols (sorbitol + mannitol). Comparison of catalytic activities of various catalysts to yield sugar alcohols from glucose is shown in Fig. 4.

3.4. Recycle study

Recyclability of Pt(2)Sn(0.25)/AL + C-HT was checked for xylose conversion up to 4 runs and showed good result with negligible decrease (2–4%) in the yield after each run. After completion of reaction, catalyst was recovered from reaction mixture by centrifugation and used in next run without drying and without calcination or reduction. The slight decrease in the yield was due to loss of some catalyst quantity during separation from reaction mixture.

4. Conclusions

The pH of reaction mixture has significant effect on the conversion of sugars and selectivity towards sugar alcohols. Combined effect of Sn (in ionic form) and solid base furnish the high yield of sugar alcohols from sugars at room temperature. Solid base help to maintain the pool of sugar molecules in open chain form. Ionic Sn polarize the C=O bond of carbonyl group of sugars. In presence of active metal i.e. Pt hydrogenation of polarized C=O bond takes place more rapidly. Very high yields of sugar alcohols i.e. 96%, 97.5%, 84% and 90% were obtained from xylose, arabinose, glucose and galactose respectively at room temperature.



Fig. 4. Conversion of glucose over various catalysts.

Reaction condition: glucose 0.15 g, catalyst 0.075 g, C-HT 0.075 g, H_2O 35 mL, 80 $^\circ C,$ H_2 16 bar at R.T. 6 h.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.carres.2021.108341.

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