Bioethanol used in Alkylation of Benzene over Modified ZSM-5 Catalysts with Nd and Pr

Parciulea AG1*, Banu I1, Rozga G1, Hubcă G1, Gaivoronschi B2 and Cincu C2

1Ministry of Education, General Berthelot, Street no. 28-30, district 1, Bucharest, Romania
2University Politechnica of Bucharest, Faculty of Applied Chemistry and Materials Science, Polizu 1-7, Bucharest, Romania

Abstract

Alkylation of benzene over new modified ZSM-5 catalysts with Nd has been done in a metallic tubular reactor. The catalyst was synthesized from components modified with NdCl3 characterized by XR-Fluorescence Spectrometer, XRD apparatus, nitrogen adsorption analyzer and TGA for its acidity. The alkylation experiments have been done at different reaction temperatures, pressures and benzene (ethylbenzene)/bioethanol molar ratio in order to establish their influence on the final composition of the reaction product, selectivity and conversion. The results obtained with Nd modified catalyst were compared with those obtained from unmodified catalyst.

Keywords: Benzene alkylation; Ethylbenzene; Zeolitic catalyst; Bioethanol.

Introduction

The alkylation of benzene (B) with ethylene over ZSM-5 zeolite is an industrial process (Mobil Badger Process) for the synthesis of ethylbenzene (EB), an important raw material in manufacturing of polystyrene and other copolymers of styrene [1]. The use of ethanol (E) instead of ethylene for benzene or toluene alkylation has been reported in other paper [2-5]. For industrial scale is very important to replace ethylene or ethanol obtained from petrochemical processes with, “bioethanol” derived from biomass, a renewable raw material. The catalytic conversion of benzene to ethylbenzene or other chemicals with bioethanol over different types of zeolites or modified zeolite catalysts has been reported earlier [6-9]. Some interesting results with high selectivity for ethylbenzene in alkylation of benzene with ethanol using a zeolite catalyst modified with lanthanum were recently reported [10].

In this work, the results of the alkylation of benzene with bioethanol (96% aqueous ethanol solution obtained from biomass) over a modified ZSM-5 zeolite with Nd cations as catalyst, were reported. We studied the influence of the catalyst, composition of the reaction mixture and alkylation process temperature, on the benzene conversion to ethylbenzene, diethylbenzene and other chemicals. Also, we compared the results obtained using the modified catalyst with Nd and the unmodified zeolite catalyst.

Experimental Part

Materials

All used chemicals were commercial (Merck, Aldrich) of high purity reagents. Aqueous ethanol solution with 96% purity (“bioethanol” in our work) was separated by distillation from aqueous high purity reagents. Aqueous ethanol solution with 96% purity and the unmodified zeolite catalyst.

The mixture of silice and alumina precursors with the molar composition 1.0 SiO2/0.01 Al2O3/1.2Na2O/0.22 H2O (hexametylene-diamine) was transformed into a microporous crystalline aluminosilicate in the presence of the binding agent (HDA). The hydrothermal synthesis was done in a stainless steel autoclave at 70-175°C, pH=12 for 48 hours and under continuous stirring. The product, Na–ZSM-5 was transformed into NH4-ZSM-5 by ionic exchange with 1M NH4NO3 solution and finally a zeolite as dry powder obtained (Z).

Synthesis of zeolitic catalyst: The powder zeolite NH4–ZSM-5(60%), alumina (40%) as a binder and nitric acid (as 10% aqueous solution) were mixed to obtain a paste. This paste was transformed into cylinders (θ=2 mm, L=5 mm) using a plunger–type extruder and the catalyst was dried (80°C, 8 hours) and calcined (550°C, 6 hours, 2°C/min) to obtain the final form of H-ZSM-5(ZC).

The chemical modification of the catalyst (ZC) was achieved by impregnation with 0.1M NdCl3, aqueous solution, dried at 80°C and calcined at 500°C to obtain ZC-Nd catalyst.

Characterization of Z, ZC, and ZC-Nd catalysts: Chemical composition of H-ZSM-5 was established using an XR-Fluorescence Spectrometer –S8-Tiger. Crystallinity and phase purity were confirmed by X-ray diffraction (XRD apparatus X’Pert PRO-MPD, PANalytical).

Nitrogen adsorption isotherms were measured at 77°C on a Micrometrics ASAP 2010 volumetric adsorption analyzer. The specific surface area was calculated by the BET method and for diameter of the pores was used the BJH method.

The acidity of the catalyst was determined by temperature programmed desorption (TPD) of diethylamine (DEA). Thermogravimetric analysis (TGA) was performed with a Du Pont Instrument device, “Thermal Analyst 2000/2100” coupled to a module 951 Thermogravimetric Analyzer. Desorption of the DEA was carried out by heating the sample from 20°C to 600°C in nitrogen atmosphere with 10°C/min.

*Corresponding author: Parciulea AG, Ministry of Education, General Berthelot, Street no. 28-30, district 1, Bucharest, Romania, Tel: 021-4056383; E-mail: parciuleaana@yahoo.com

Received May 22, 2015; Accepted May 23, 2015; Published June 01, 2015

Citation: Parciulea AG, Banu I, Rozga G, Hubcă G, Gaivoronschi B, et al. (2015) Bioethanol used in Alkylation of Benzene over Modified ZSM-5 Catalysts with Nd and Pr. Chem Sci J 6: 96. doi:10.4172/2150-3494.100096

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Alkylation reaction

The alkylation reaction was performed in a metallic reactor (Figure 1). Details about the reactor have been reported earlier [11,13]. The experiments were done at 250-450°C with different molar ratio B/E (1/1, 2/1 and 3/1) at 2 bar pressure and at feeding flow rate of 2.5 mL/min. The nitrogen was used as carrier gas (30mL/min). The reaction mixture was analyzed by gas chromatography to establish its chemical composition (Varian CP3800 apparatus coupled with MS Varian 4000).

Results and Discussion

The properties of H-ZSM-5 zeolite powder (Z), H-ZSM-5/Al₂O₃ (ZC) and H-ZSM-5/Al₂O₃ modified with Nd (ZC-Nd) materials are presented in the Table 1. We selected a H-ZSM-5 with the ratio SiO₂/Al₂O₃≈100 according to the results presented in the literature [3]. This type of catalyst gives a high selectivity for EB in alkylation process of benzene with ethanol. For ZC catalyst BET surface area and pores volume are smaller than for Z zeolite because Al₂O₃ used as binder is a mesoporous material. There are not important modifications when ZC is transformed into ZC-Nd catalyst (Table 1). The XRD analysis of zeolitic material (Z) showed (Figure 2) a well crystallized material with specific MFI lattice [14].

The values of acid strength (the loss with temperature of DEA in mE/g catalyst) for ZC and ZC-Nd catalysts are presented in Table 1 and on the (Figures 3 and 4). There are three delimited zones (A, B, C) on the graphs which are assigned to the week, medium and strong acidity. The presence of the Nd cations reduces the total acidity (increased loss of DEA) and will influence its activity in alkylation process. The chemical composition (%) of the reaction mixtures (benzene, ethylbenzene, diethylbenzene-DEB, xylene-X, trimethylbenzene-TMB, methylethylbenzene-MEB) using ZC and ZC-Nd catalysts are presented on the (Figures 5-7).

Lanthanides (including Pr, Nd) have electrons in “f” sheath (layer) which gives the possibility to form complexes and high catalytic activity in chemical reaction as benzene alkylation. From those results we observe a reduction of benzene reactivity (increased concentration of unreacted benzene) in alkylation process in the presence of ZC-Nd catalyst in comparison with ZC catalyst.

We suppose that this phenomenon is explained by the reduction of the total acidity of ZC-Nd catalyst due to the adsorption of Nd cations on the acid centers. The ionic radius of Nd³⁺ is ≈0.995 Å, so it can enter into all micropores (diameter=3.40 nm, Table 1) of the catalyst.

Table 1: Properties of the catalysts: Z, ZC and ZC-Nd.

| Properties                  | Z    | ZC   | ZC-Nd |
|-----------------------------|------|------|-------|
| SiO₂, mole%                 | 8.6  | 8.6  | 8.6   |
| Al₂O₃, mole%                | 1.03 | 1.03 | 1.03  |
| Na₂O, mole%                 | 0.37 | 0.37 | 0.37  |
| SiO₂/Al₂O₃ mole/mole         | 96   | 96   | 96    |
| Pores diameter, nm          | 3.51 | 3.40 | 3.40  |
| BET surface area, m²/g      | 410  | 300  | 291   |
| Micropores surface area, m²/g| 255  | 170  | 170   |
| Total volume pores, cm³/g   | 0.323| 0.103| 0.100 |
| Micropores volume, cm³/g    | 0.357| 0.089| 0.089 |
| Nd content, %               | 3.01 | 3.01 | 3.01  |
| Acidity (loss of DEA) (mE/DEA/g)/%| 0.486/100 | 0.685/100 | 0.685/100 |
| Weak                        | 0.206/42.5 | 0.378/55.2 | 0.378/55.2 |
| Medium                      | 0.164/33.7 | 0.165/24.1 | 0.165/24.1 |
| Strong                      | 0.116/23.8 | 0.142/20.7 | 0.142/20.7 |

Figure 1: Alkylation reactor 1) Reactor body 2) Catalyst zone 3) Inert zones 4) Inert zones 5) Flanges 6) Flanges 7-11) Thermocouples, S: Reaction mixture supply, E: Exit of reaction products

Figure 2: XRD diffractogram for ZSM-5 zeolite synthesized in the presence of hexamethylenediamine.

Figure 3: The loss of DEA with temperature for ZC catalyst.
Figure 4: The loss of DEA with temperature for ZC-Nd catalyst.

Figure 5: Concentration of the components in reaction mixture as a function of the temperature catalysts ZC (-----) and ZC-Nd (___).

Figure 6: Concentration of the components in reaction mixture as a function of the temperature catalysts ZC (-----) and ZC-Nd (___).
The concentration of EB in reaction mixture increases with temperature in the region (250-450°C) for all ratios B/E. The modified catalyst with Nd gives a better result increased concentration of EB in comparison with ZC catalyst only for the ratio B/E=2/1 mole/mole at 350-450°C. In the case of mixture B/E=3/1 mole/mole the catalyst ZC-Nd is more selective for DEB than ZC-catalyst (Figure 7 curves DEB and DEB-ZC).

Conclusions
1. The synthesized zeolitic material Z has a well crystallized structure with specific MFI lattice.
2. Chemical modification of ZC catalyst with Nd cations decreases its acidity and reactivity of benzene in alkylation process;
3. For both catalysts (ZC and ZC-Nd) the concentration of EB in reaction mixture increases with temperature between 250°C-450°C for all ratios B/E;
4. The catalyst ZC-Nd gives a reaction mixture with a higher concentration in EB, than ZC catalyst only in a particular case: B/E=2/1 mole/mole and T=350°C-450°C;
5. In the case of initial mixture B/E =3/1 mole/mole, the catalyst ZC-Nd has a higher selectivity for DEB than ZC catalyst.

References
1. Dwyer FG, Lewis PJ, Schneider FM (1976) Chem Eng 83: 90.
2. Yuan JJ, Gevert BS (2006) Alkylation of benzene with aqueous solution of ethanol over ZSM-5 catalysts. Indian Journal of Chemical Technology 13: 334-340.
3. Yuan JJ, Gevert BS (2004) Alkylation of benzene with ethanol over ZSM-5 catalyst with different SiO2/Al2O3 ratios. Indian Journal of Chemical Technology 11: 337.
4. Dandekor AB, Degnon TF, Mc Williams JP, Venkat CR (2003) US Patent.
5. Bhat YS, Dos J, Halgeri AB (1995) Coke Induced Stabilization of Catalytic Activity of Silylated ZSM-5 Zeolite. J Catal 155: 154.
6. Sridevi U, Bhushar Rao BK, Pradhan NC (2001) Kinetics of alkylation of benzene with ethanol on AlCl3-impregnated 13X zeolites. Chem Eng J 83: 185.
7. Walendziewski J, Trawczynski J (1996) Alkylation of Toluene with Ethanol. Ind Eng Chem Res 35: 3356.
8. Sabu KR, Rao KVC, Nair CGR (1994) Alkylation of Benzene, Toluene and Xylene Isomers with C-2, C-3 and C-4 Aliphatic-Alcohols on TiO2-SiO2-Al2O3 and MoO3-SiO2-Al2O3 Catalysts. Indian J Chem 33B: 1053.
9. Loredano L, Benicini E, Casalini A (2012) Process for the alkylation of benzene with ethanol or mixtures of ethanol and ethylene. Brevet EP 20100728287/12.
10. Li JH, Nan WY, Jun H, Zhirong Z (2012) Alkylation of Benzene with Ethanol on Zeolites Modified with La2O3. Advanced Materials Research 347-353: 3670.
11. Parciulea AG, Hubcă G, Cincu C (2013) Alkylation of benzene with bioethanol on modified zeolitic catalyst. Materiale Plastice 50: 167-170.
12. Parciulea AG, Hodoșan C, Nistor L, Hubcă G, Cincu C (2014) Revista Chimie (Bucharest) 65: 590.
13. Final report of Contract 861/26.11.2010 Biosint EB SRL –ANCS, Bucharest, Romania.
14. Baerlocher CH, Meier WM, Olson DH (2001) “Atlas of Zeolite From work Types” the fifth
15. Revised (edn) Elsevier Science, UK