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Zeolite catalysis for a better environment

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Abstract

To meet the regulations of The Clean Air Acts, solid acid alkylation and isomerization of alkanes and naphthenes have become important processes for producing high-octane blending components in gasoline. To reduce the costs associated with filtration and disposal of chemical waste, the chemical industry has to switch from homogeneous or unsupported heterogenous catalysts to supported catalysts. Zeolite catalysts are playing an ever-increasing role in the petroleum refining and chemicals manufacturing processes. In the areas of acid catalysis by zeolites, recent publications on isobutane alkylation, alkane isomerization, alkene interconversion and isomerization, phenol alkylation and oxygenate production are reviewed. Also reviewed in the areas of basic zeolite catalysis is the patent literature on isomerization of propylene oxide to allyl alcohol, double-bond isomerization of alkenes and ethoxylation of glycol.

1. Introduction

More stringent environmental regulations have driven the petroleum refiners to produce transportation fuels with low sulfur and aromatics and the chemical industry to reduce the costs for waste disposal. To meet the regulations of the 1990 Amendments to the Clean Air Acts, alkylate is a preferred blending component for reformulated gasoline under both the simple and complex models. As a result of the hazardous properties of liquid acids employed in the current alkylation processes, the new processes under development center around more environmentally-benign catalysts. Isomerization of alkanes has also become an important process for producing high-octane blending components in gasoline. To reduce the costs associated with filtration and disposal of chemical waste, the chemical industry needs to switch from homogeneous catalysts or unsupported solid catalysts to supported catalysts. This overview will cover recent developments in zeolite catalysis for meeting the objectives of refining and chemical processes targeted at creating a better environment tomorrow. More specifically, the zeolite catalysts for solid acid alkylation, isomerization of alkane, interconversion and isomerization of alkenes, alkylation of phenol and production of oxygenates are reviewed. In the area of base catalysis, the recent development of zeolite-supported catalysts in the patent literature for ring opening isomerization of propylene oxide, double-bond isomerization, and alkoxylation of alcohols are discussed.

2. Acid catalysis for refining processes

2.1. Solid acid alkylation

A new heading

High-octane alkylates have been produced for decades from isobutane and butenes using the liquid acids such as sulfuric and hydrofluoric acid as

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Table 1
Comparison of activities in isobutane alkylation with 2-butene between REY and MCM-36 zeolites

Catalyst type	75/25 REY/ Al_2O_3		75/25 REY/ Al_2O_3		65/35 MCM-36/Al_2O_3	
Temperature	93.3°C		121°C		149°C	
Catalyst age, g/g	0.2	0.7	0.2	0.8	0.7	7.1
Conversion, %	100	55	100	58	96	68
C_{5+} yield, g/g	1.1	1.1	1.1	1.4	1.6	1.7
Wt.-% of C_{5+}						
C_5–C_7	30	12	36	23	24	20
C_8	49	35	53	44	61	63
C_{9+}	21	54	11	34	15	18
TMP	30	5	28	17	43	31
Wt.-% of C_8						
TMP	60	15	52	39	70	49
DMH	36	39	43	41	27	28
TMP/DMH	1.7	0.4	1.2	1.0	2.6	1.7

Mobil, US Patent 5 258 569 (1993) [4].
Fixed-bed reactor, 0.045 h^{-1}, 50:1 isobutane:2-butene, 500 psig.
TMP: Trimethylpentane, DMH: dimethylhexane.

catalysts. The environmental requirements and process safety associated with liquid acids continue to drive the industry to develop solid acid alkylation technologies. In fact, several major process licensors are well on their way to bringing these new technologies onto the market.

Table 2
Comparison of activities in isobutane alkylation with 2-butene between MCM-22 and MCM-49 zeolites

Catalyst type	65/35 MCM-22/Al_2O_3			65/35 MCM-49/Al_2O_3		
Catalyst age, g/g	0.5	2.7	5.8	0.2	0.7	2.9
Conversion, %	86	72	58	100	65	43
C_{5+} yield, g/g	1.6	1.7	1.5	1.4	1.6	1.7
Wt.-% of C_{5+}						
C_5–C_7	26	20	18	34	22	20
C_8	60	65	68	57	61	66
C_{9+}	14	15	14	91	81	5
TMP	42	41	36	38	37	34
Wt.-% of C_8						
TMP	70	64	53	66	62	51
DMH	22	20	19	27	20	18
TMP/DMH	3.2	3.2	2.8	2.5	3.0	2.8

Mobil, WO 93/07106 (1993) [5].
Fixed-bed reactor, 0.045 h^{-1}, 50:1 isobutane:2-butene, 149°C, 500 psig.
TMP: Trimethylpentane, DMH: dimethylhexane.

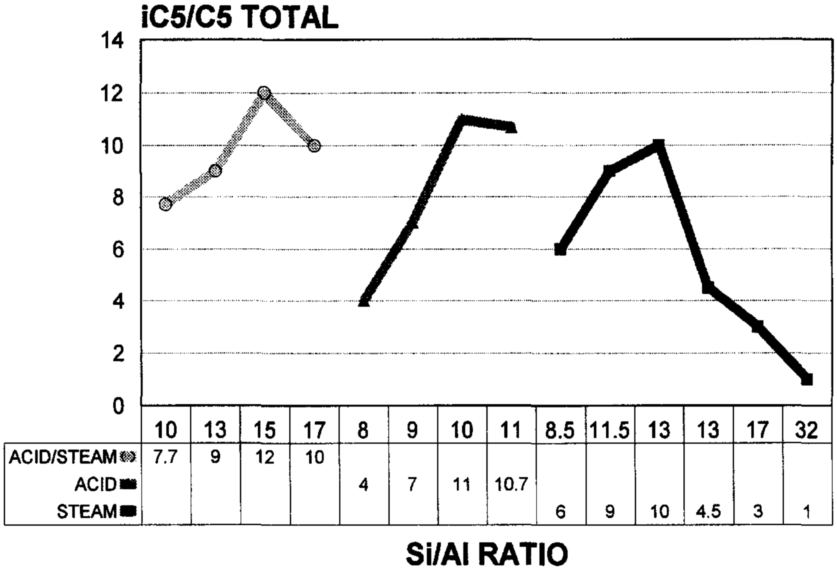
Much research work has been conducted to explore the potential of zeolites as catalysts for the alkylation of isobutane with alkenes. Corma and Martinez [1] has recently reported an extensive review on the actual situation and future trends on solid acid alkylation. The fresh zeolites do catalyze the alkylation. The products obtained from zeolite catalysts have octane number and product compositions in common with alkylates from liquid acids. However, zeolites suffer a rapid loss in activity and a severe degradation in selectivity to trimethylpentanes (TMP).

Mobil Oil has patented many process/catalyst combinations incorporating BF_3 as a promoter [2,3]. Their work showed that the use of a large-pore zeolite in combination with a Lewis acid greatly increased the activity and selectivity in the alkylation reaction. The results in Table 1 and Table 2 illustrate the performances of novel large-pore MCM-22, MCM-36 and MCM-49 zeolites in isobutane alkylation with 2-butene. It is seen that the initial TMP selectivity is up to 70 wt.-% in the total C_8 fraction [4,5]. It appears that an ideal and successful zeolite catalyst for alkylation should meet the following requirements. The zeolite should have large-pore structures, strong acidity and a high hydrogen-transfer rate. Moreover, it should not promote oligomerization of alkenes.

2.2. *Isomerization of alkane*

The bifunctional Pt on mordenite catalyst is widely used in hydroisomerization processes for upgrading the octane number of the C_5/C_6 light naphtha. The acid strength of zeolites depends on two factors: the framework Si/Al ratio and the T–O–T angle. It is known that zeolites with the same Si/Al ratio prepared by different procedures could give distinct performances.

In this work [6], dealuminated mordenites obtained by three procedures: acid treatment, mild steaming, and acid treatment followed by mild



	10	13	15	17	8	9	10	11	8.5	11.5	13	13	17	32
ACID/STEAM ●	7.7	9	12	10										
ACID ■					4	7	11	10.7						
STEAM ■									6	9	10	4.5	3	1

Fig. 1. Light straight run naphtha isomerization over mordenite.

steaming were evaluated for light straight run naphtha (60% n-C_5 and 40% n-C_6) at 250°C, 30 bar, LHSV = 35 and H_2/HC = 1 mol/mol. The catalyst was loaded with 0.5% Pt. It is seen from Fig. 1 that for each series of dealuminated mordenites, there exists a maximum in activity at different framework silica-to-alumina ratios (SAR). The maximum activity was found for the mordenite treated first with acid and then with mild steaming.

In order to explain these results, it must be considered that the dealumination process modifies the framework Al content (FAL), pore size distribution, and quantity of extraframework Al (EFAL) species. The i-C_5/C_5 (isopentane/total pentanes) activity is plotted against the FAL/EFAL ratio in Fig. 2. The optimum was found for a FAL/EFAL ratio of about 3. The results demonstrate that a small and controlled quantity of EFAL can produce a synergistic effect on the Brønsted acid site of the zeolite.

The isomerization of light paraffinic naphtha over a Beta zeolite catalyst was recently reported in the patent literature [7]. The performance of Beta zeolite was compared with the UOP's I-7 catalyst at constant temperature, e.g. 262°C, in Table 3. The activity for isopentane conversion was much higher for Beta than a mordenite-based I-7 catalyst (68.2 vs. 51.9). The activity for the production of 2,2-dimethylbutane (DMB) was only slightly higher for Beta than that observed for I-7. Since Beta zeolite was more active for isomerization and cracking, the C_{5+} (pentane and heavier) yield was lower for Beta than I-7. The research octane number of the isomerate product is comparable for both zeolites.

At a constant C_{5+} yield of 95% (shown in Table 4), conversion to 2,2-DMB was actually lower for Beta zeolite than I-7. However, Beta zeolite showed an advantage in the activity for total isohexane production and isopentane production. As a result, an isomerate with the same research octane number (RON) can be obtained at about 25°C lower reaction temperature with the Beta zeolite catalyst.

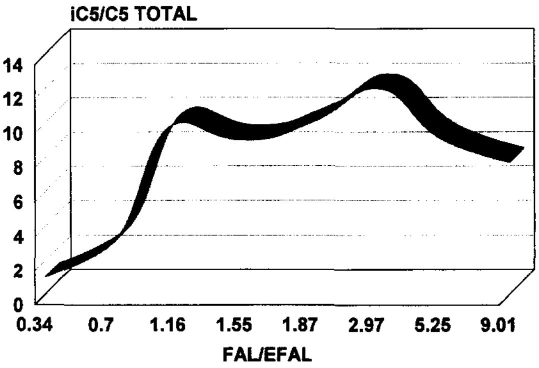


Fig. 2. Effect of EFAL/FAL ratio on isopentane selectivity.

Table 3
Isomerization of light naphtha over Beta and mordenite zeolites (compared at constant temperature, 262°C)

	Beta	I-7, mordenite
C_{5+} yield, %	87	95
Product RON	76	74
$i\text{-}C_5$/total C_5, %	68.2	51.9
2,2-DMB/total C_6, %	14.9	14.1
$i\text{-}C_6$/total C_6, %	81.9	79.9

Table 4
Isomerization of light naphtha over Beta and mordenite zeolites (compared at constant 95% C_{5+} yield)

	Beta	I-7, mordenite
Temp. required (°C)	237	262
Product RON	74	74
$i\text{-}C_5$/total C_5, %	53.7	52
2,2-DMB/total C_6, %	10	14.1
$i\text{-}C_6$/total C_6, %	81	79.9

Table 5
Activities of SAPO molecular sieves in the skeletal isomerization of n-hexane

Catalyst	$n\text{-}C_6$, conv. wt.-%	$iso\text{-}C_6/C_6$, wt. ratio
SAPO-34	40–50	1
SAPO-5	10–20	2
Cl/alumina	30–70	2–3
SAPO-41	50–60	5–6
SAPO-11	40–60	9–11

482°C, 200 psig reforming conditions.

Table 6
Isomerization of n-octane over Pt catalysts

Catalyst	SiO_2–Al_2O_3	HY	ZSM-5	SAPO-5	SAPO-11
Temp., °C	371	257	260	304	331
$i\text{-}C_8$ sel., wt.-%	96.4	96.8	56.6	49.3	94.8
$2M\text{-}C_7/3M\text{-}C_7$	0.67	0.71	1.54	0.46	1.07
C_3+C_5/C_4, mol ratio	0.95	0.64	2.1	0.86	1
$DM\text{-}C_6$ sel., wt.-%	8.5	12	1.8	9	2.3

1000 psig, 2.8 WHSV, 16 H_2/HC, and 30% conversion.

The silicoaluminophosphate (SAPO) molecular sieves have shown catalytic activity for a broad array of refining and petrochemical reactions. Pellet et al. reported [8] that for hexane isomerization medium-pore SAPO-11 (3.9×6.3 A, AEL) and SAPO-41 (4.3×7.0 A, AFO) molecular sieves produced 2–4 times greater isohexane than the Pt catalyst on chlorided alumina (shown in Table 5). In contrast, both small-pore SAPO-34 and large-pore SAPO-5 were not as effective as chlorided alumina.

Very recently, Miller [9] studied the hydroisomerization of n-octane over three catalysts each loaded with 1 wt.-% Pt under the conditions (1000 psig, 2.8 WHSV, 16 H_2/HC, and 30% conversion). As shown in Table 6, SAPO-11, SiO_2–Al_2O_3 (SA) and HY all had high isomerization selectivity of n-C8 (> 90%). Unlike SA and HY, the SAPO-11 gave a high $2M\text{-}C_7/3M\text{-}C_7$ ($M\text{-}C_7$; methylheptane) ratio, indicative of medium-pore size. Another feature of SAPO-11 was that it showed low selectivity to dimethylhexane ($DM\text{-}C_6$).

It can be concluded from the above studies that the zeolite Beta and medium-pore SAPO molecular sieves such as SAPO-11 and 41 exhibited improved C_6 isomer yield compared to chlorided alumina and mordenite catalysts. The future challenge in isomerization is to co-process higher boiling point C_7 alkane and to perform ring-opening reaction of naphthenes while achieving high-octane number through multiple branching.

2.3. Alkene interconversion and isomerization

There has been renewed interest in the interconversion and skeletal isomerization of light alkenes. The research efforts were stimulated by the need for more isobutylene and isoamylene as the raw materials for the production of oxygenates. To date, there are a number of commercial skeletal isomerization processes available for licensing. Zeolites with TON structure such as Theta-1 and ZSM-22 [10,11], FER [12] and MEL structures such [B]-ZSM-11 [13] are claimed as the effective catalysts for these processes.

The product slate from the interconversion of light alkenes can be adjusted by changing the feed-

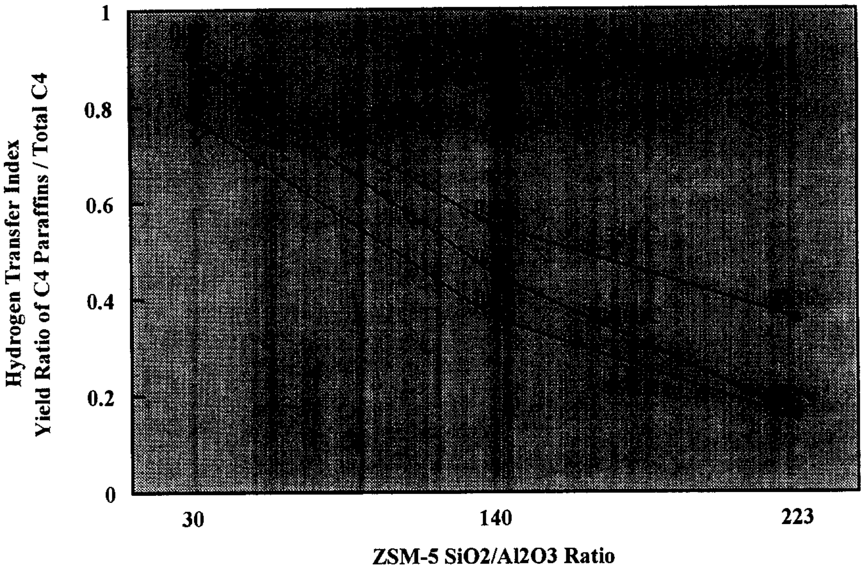


Fig. 3. Effects of the silica/alumina ratio and temperature on the hydrogen transfer index. (▲) 350°C. (◆) 400°C. (▼) 450°C.

stock, operating parameters, and catalysts. The olefinicity of the product can be controlled by manipulating the pore size and acidity of zeolites. For instance, over the ZSM-5 zeolites propylene ($C_3^=$) can be converted primarily to C_4–C_5 alkenes and alkanes at moderate temperatures [14]. As seen in Fig. 3 the ratio of alkanes to alkenes decreases with the increasing silica-to-alumina ratio of the ZSM-5 zeolites. The olefinicity of the product is governed by the bimolecular hydride transfer reaction.

MCM-22, ZSM-5 and amorphous SA are compared for their performances in the conversion of propylene to isoalkenes in Fig. 4 [15,16]. One can see that MCM-22 required an approximately 50°C higher temperature to obtain a $C_3^=$ conversion which was the same as the ZSM-5 catalyst. MCM-22 produced less alkene and more C_5-(lighter than pentane) saturates than ZSM-5. The results implied that hydrogen transfer and cracking reactions were more favorable in the MCM-22 because of its 12 ring pore and 18 Å cages. The [B]-MCM-22 greatly improved the catalyst aging rate over the [Al]-MCM-22 zeolite.

Medium-pore SAPO, MeAPO and MeAPSO molecular sieves also promote alkene isomerization and oligomerization while they are significantly less effective for the competing hydride transfer and cracking reactions. As shown in Fig. 5, in the skeletal isomerization of 1-butene, MgAPSO-31 gave up to 50% conversion and 80% selectivity to isobutene over the temperature range of 370–570°C and WHSV of 46–139 [17].

Yang et al. [18] investigated the 1-butene conversion over the medium-pore SAPO-11 and MeAPO-11 molecular sieves. These materials were also studied for their product distributions in 2-butene isomerization [19,20]. SAPO-11 and CoAPO-11 were more selective for the production of isobutene than FeAPO-11 and FeAPO-31.

Ferrierite (FER) has been found to be an excellent catalyst for the skeletal isomerization of n-butene as the isobutene selectivity could be up to 90% at the conversion levels of 40% and above [21,22]. A process based on these Shell's findings has now successfully been demonstrated on a 3000 BPD (barrel/day) pilot plant by Lyondell/CD Tech, with a FER catalyst manufactured by Zeolyst International.

3. Acid catalysis for chemical processes

3.1. *Alkylation of phenol with nonenes*

Alkylphenol is manufactured by the reaction of phenol with various alkenes in the presence of an

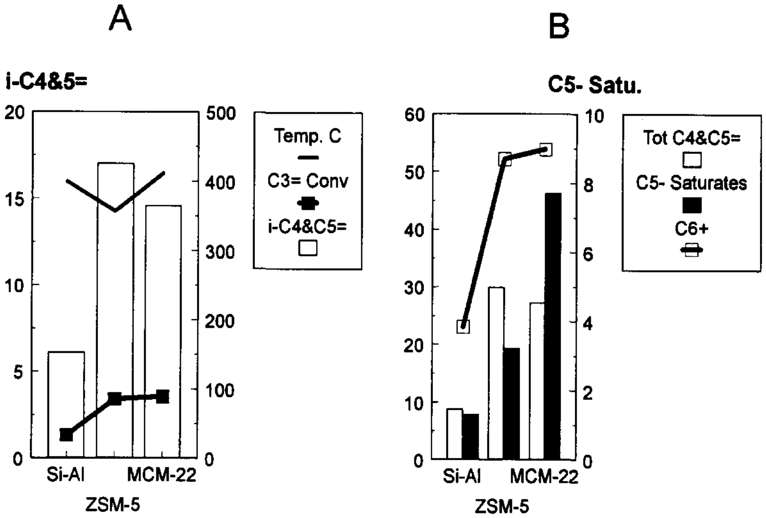


Fig. 4. Olefin interconversion process using MCM-22 (data from US Patent 5 146 029 of Bundens et al.) [15].

acidic catalyst such as a mineral acid (e.g. HF), a Lewis acid (BF_3) or a cation-exchange resin. The conventional technology which employs mineral acids or Lewis acids requires neutralization, regeneration and incineration of spent acids. The state-of-the-art technology is now based on a fixed-bed solid acid catalyst, thus, reducing a significant portion of the investment costs for acid handling and minimizing the environmental problems.

Knifton et al. [23] investigated the catalytic activities of zeolites for the alkylation of phenol with nonenes. It is most desired to produce a high yield of *para*-nonylphenol and to minimize the yield of dinonylphenol. They found that a high *para*/*ortho* ratio (> 7) and high ratio of mono-/di-nonylphenol (mnp/dnp: 6–74) could be obtained over USY and Beta zeolites (shown in Table 7). By contrast, mordenite and ZSM-5 were much less effective than USY in the synthesis of nonylphenol.

Compared to HF/Clay 24 catalyst, large-pore zeolites were less active for nonene conversion. However, zeolites gave higher *para*/*ortho*-isomer ratios and mnp/dnp ratios than clay catalysts. Large-pore molecular sieves having high total acidities are needed for further enhancing the productivity of alkylphenol. In the near future zeolite catalyst will also replace HF currently employed in the alkylation of aromatics, particularly ben-

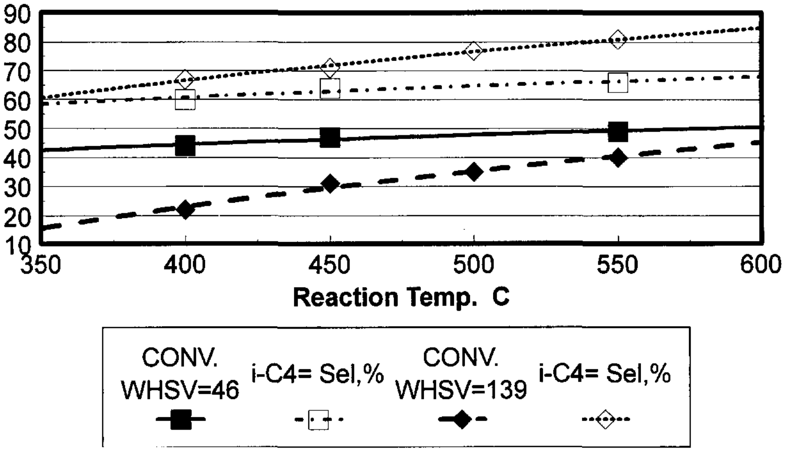


Fig. 5. Skeletal isomerization of 1-butene with MgAPSO-31 (data from USP 5 107 050 of Gaffney and Jones) [17].

Table 7
Comparison of catalyst activities for alkylation of phenol with nonenes

Catalyst	SAR	Nonene, conv. %	NP, conc. %	*p*-NP/*o*-NP	NP/DNP
Zelon 900H	12	2.3	2.4	7.6	0
CP316-26	46	72	50	9.4	6.4
CP308-51	5.3	52	49	15.3	74
SK-500	2.9	53	39	10.1	7.1
LZ-Y82	7.8	44	36	10.1	45
C861B	24	63	52	6.9	25
HF/Clay 24	24	94	67	6.1	9

120°C. LHSV = 1. Feed-rate 400 cm^3/h.
$PhOH/C_9H_{18} = 1.34$ mol/mol.

zene alkylation for the production of linear alkylbenzene.

3.2. Production of oxygenates

Oxygenates are used as gasoline blending components, octane boosters and as key ingredients for reducing the emissions of CO and volatile organic compounds (VOC). Of all oxygenates, the tertiary ethers such as methyl t-butyl ether (MTBE), ethyl *t*-butyl ether (ETBE), and *t*-amyl methyl ether (TAME) are preferred by refineries to lighter alcohols. They have lower blending Ried vapor pressure, low vaporization latent heat and low solubilities in water. The most common ether in use today is MTBE with a production capacity of about 25 million metric tons. MTBE or ETBE are produced by reacting isobutylene with either methanol or ethanol in the presence of an acidic resin catalyst. An alternative route is by the reaction of *t*-butanol with alcohols. Some of the recent developments in the production of ethers using zeolite catalysts are discussed below.

Bell and Haag [24] reported a catalytic process for the manufacture of methyl isopropyl ether from a propylene feed and methanol by contact with a zeolite such as Beta or ZSM-5 zeolite. The activity appeared to decrease in the order of Beta > ZSM-5 > ZSM-12 > USY. Harandi et al. [25] disclosed a process for synthesizing di-isopropyl ether (DIPE). They found that the unbound Beta and zirconia-bounded Beta are more effective than the alumina bounded Beta. ZSM-35 and ZSM-5 zeolites were much less active than Beta and Y zeolites for etherification of isopropanol (IPA). Very recently, Bell and Haag [26] reported that a hydrothermally treated Beta was particularly effective in reducing the formation of by-product dimer, thereby, giving a high MTBE selectivity. Knifton et al. [27] have patented an improved process for preparing MTBE in one step from methanol and a *t*-butanol feed containing peroxides and formate. They found that Y zeolites impregnated with a low loading of Fe, Cu, Cr, and Mn give not only good MTBE selectivity but also high activity for decomposition of peroxides which are poisons to acidic resin catalysts.

4. Solid base catalysis

Turning to base catalysis, in addition to classical side-chain alkylation, Aldol condensation and dehydration of isopropanol, new applications of neutralized or basic zeolite supports have recently been reported in the patent literature. The common objectives for developing solid base catalysts are to improve the selectivity, to improve the product quality, and to reduce the production costs associated with separation of the catalyst in the slurry-phase process, neutralization of residual caustic catalysts and filtration, and disposal of solid waste.

4.1. PO isomerization to allyl alcohol

Ring opening isomerization of propylene oxide (PO) was suggested to be a very useful test for the characterization of solid bases. Over basic oxides, PO is converted to acetone, whereas, over acidic oxides it is isomerized to propanal. The discovery that alkylene oxides rearrange to give allylic alcohols in the presence of basic lithium phosphate catalysts sparked years of industrial research aimed at improving catalyst lifetime and productivity. Allyl alcohol is converted either to useful allyl derivatives or to 1,4-butandiol through hydroformylation.

Table 8
Gas phase isomerization of propylene oxide to allyl alcohol using supported lithium phosphate catalysts

Catalyst support	p/o conv., %	Allyl alcohol select.	1-Propanol select.
NaY	73	89	0.8
Na mordenite	55	87	1
MgO	22	67	6
CaO	12	15	40
γ-Alumina	48	15	8

All catalysts contain 37% Li_3PO_4.
300°C, WHSV 2.3/h (US Patent 5 262 371 to M.K. Faraj, ARCO Chemicals) [28].

Table 9
Effect of supports on the selectivity in double-bond isomerization of alkenes

Catalyst	Cracking, wt.-%	Double-bond isom., mol-%
NaX	62.3	10.3
$Ca(OH)_2/NaX$	0.4	45.9
NaY	8.7	36.5
$Ca(OH)_2/NaY$	0.6	49.9
$Mg(OH)_2/NaY$	0.3	78.3

1-Octene flow-rate 10 g/h, 400°C, 14 cm^3 catalyst (US Patent 5 053 372 to Brownscombe, Shell, 1991) [29].

Table 10
Effect of K_2O loading on the selectivity in double-bond isomerization of alkenes

Catalyst	Conv., %	1-Oct.	2-Oct.	3-Oct.	Double-bond isom.
NaY	33.4	67.6	15.7	12	85.4
Low-base K_2O/ NaY	10.5	89.5	3.6	3.9	71.4
High-base K_2O/ NaY	52.5	47.5	19.1	32.1	97.5

[a] 1-Octene flow-rate 68/h, 400°C, 33 cm^3 catalyst (US Patent 5 194 244 to Brownscombe, Shell, 1993) [29].

In the gas phase isomerization of PO to allyl alcohol, the effect of supports on the performances of supported lithium phosphate catalysts was studied [28]. It can be seen in Table 8 that neutral supports such as NaY gave high selectivity and excellent activity. In contrast, lithium phosphate on acidic supports such as γ-alumina and basic supports such as CaO gave relatively low conversions and selectivities.

4.2. *Double-bond isomerization of alkenes*

Double-bond isomerization is an important process for the preparation of detergent range (C_{10}–C_{18}) or additive range (C_4–C_8) alkenes from α-alkenes. To improve the selectivity to double-bond isomerization, Brownscombe [29] has patented a catalyst which comprised a zeolite impregnated with an alkali metal in excess of that required to provide a fully metal cation-exchanged zeolite. NaY impregnated with alkali metal or alkaline earth oxides, as shown in Table 9, exhibited high isomerization yields and low yields to undesirable cracking products [29]. It was shown in Table 10 that with NaY impregnated with 20 equivalents of K per supercage the selectivity for double isomerization of 1-octene was 97.5% while NaY gave a selectivity of 85.4%.

4.3. *DEG ethoxylation*

To replace caustic catalysts currently used in the ethoxylation of alcohols, Cuscurida et al. [30] disclosed a process for producing narrow range glycols which comprised reacting a glycol with ethylene oxide in the presence of a solid base catalyst. Alkali metal or alkaline earth oxides impregnated onto various zeolite/alumina supports appeared to be effective catalysts for the reaction of ethylene oxide (EO) with diethylene

Table 11
Catalyst screening studies for DEG alkoxylation using 20% CsCl supported catalysts [30]

Support	SAPO-34	KL	Beta	NaY
Cat. conc., wt.-%	2	2	2	2
Temp., °C	150	146	151	151
DEG conv., %	63	63.4	68.7	67.7
Selectivity, %				
TEG	58.4	65.9	60.3	62.6
T4EG	27.4	26.1	27.7	27
T5–T8EG	10.5	7.6	9.2	8.4

glycol (DEG), and offers a promising approach in controlling the molecular weight distribution of glycol products.

As shown in Table 11, the SAPO-34, KL, Beta, and NaY zeolite/alumina supports impregnated with 20% CsCl exhibited comparable DEG conversions and similar distributions of oligomer products (TEG:trimer; T4EG:tetramer; T5–T8EG:pentamer–octamer). The results suggest that the reaction most likely occurred on the exterior surface of the zeolites since there was significant differences between the activities of SAPO-34, a small-pore zeolite, and KL, a large-pore zeolite. Of these four catalysts, KL zeolite warrants further research work since it gave a selectivity to the undesired T5–T8EG fraction much lower than the liquid KOH catalyst.

5. Conclusions

Zeolite catalysts will continue to play an important role in petroleum refining and chemical manufacturing processes as companies strive to meet new environmental regulations and to minimize chemical releases. Much work is needed to develop a zeolite-based catalyst technology for solid acid alkylation. Acidity and pore size control are important factors in designing a bifunctional catalyst for maximizing the isomerization yield, particularly for processing C_{7+} alkane and naphthenes. Acidic and basic zeolites will take the place of liquid acids and bases as catalysts in the alkylation and alkoxylation processes. Multifunctional catalysts will be derived from a proper selection of zeolites and metals of catalytic interest for chemical processing to improve product selectivity and minimize chemical waste. Medium and large-pore SAPO and MeAPO molecular sieves could offer new applications in the areas of base-catalyzed and selective oxidation reactions.

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