

N-OLEFIN SKELETAL ISOMERIZATION PROCESS

This invention relates to a process for the skeletal isomerization of n-olefin-containing, e.g., n-butene-containing, hydrocarbon streams to iso-olefin-rich, e.g., isobutene-rich product streams.

The demand for iso-alkenes has recently increased in response to a greater demand for oxygenated gasoline additives. For example, relatively large amounts of isobutene are required for reaction with methanol or ethanol over an acidic catalyst to produce methyl tert-butyl ether (MTBE) or ethyl tert-butyl ether (ETBE) which is useful as an octane enhancer for unleaded gasolines. Isoamylenes are required for reaction with methanol over an acidic catalyst to produce tert-amyl methyl ether (TAME). With passage of the Clean Air Act in the United States mandating increased gasoline oxygenate content, MTBE, ETBE and TAME have taken on new value as clean-air additives, even for lower octane gasolines. Lead phasedown of gasolines in Western Europe has further increased the demand for such oxygenates.

An article by J.D. Chase, et al., Oil and Gas Journal, April 9, 1979, discusses the advantages which can be achieved by using such materials to enhance gasoline octane. The blending octane values of MTBE when added to a typical unleaded gasoline base fuel are RON = 118, MON = 101, R+M / 2 = 109. The blending octane values of TAME when added to a typical unleaded gasoline base fuel are RON = 112, MON = 99, R+M / 2 = 106. Isobutene (or isobutylene) is in particularly high demand as it is reacted with methanol to produce MTBE.

The addition of shape-selective zeolite additives such as ZSM-5 to cracking catalysts, e.g. those used in fluidized catalytic cracking (FCC), is beneficial in producing gasoline boiling range product of

increased octane rating. However, increased amounts of olefins result, including n-butenes, creating a need for their conversion to higher value products such as isobutene which can be used to produce MTBE.

5 Butene exists in four isomers: butene-1, cis-butene-2, its stereo-isomer trans-butene-2, and isobutene. Conversion between the butene-2 isomers is known as geometric isomerization, whereas that between butene-1 and the butene-2 isomers is known as position
10 isomerization, double-bond migration, or hydrogen-shift isomerization. The aforementioned three butene isomers are not branched and are known collectively as normal or n-butenes. Conversion of the n-butenes to isobutene, which is a branched isomer, is widely known
15 as skeletal isomerization.

The reaction of tertiary olefins with alkanol to produce alkyl tertiary alkyl ether is selective with respect to iso-olefins. Linear olefins are unreactive in the acid catalyzed reaction, even to the extent
20 that it is known that the process can be utilized as a method to separate linear and iso-olefins. The typical feedstream of FCC C₄ or C₄+ crackate used to produce tertiary alkyl ethers in the prior art which contains normal butene and isobutene utilizes only the
25 branched olefin in etherification. This situation presents an exigent challenge to workers in the field to discover a technically and economically practical means to utilize linear olefins, particularly normal butene, in the manufacture of tertiary alkyl ethers.

30 In recent years, a major development within the petroleum industry has been the discovery of the special catalytic capabilities of a family of zeolite catalysts based upon medium pore size shape selective metallosilicates. Discoveries have been made leading
35 to a series of analogous processes drawn from the

catalytic capability of zeolites in the restructuring of olefins.

5 EP-B-26041 discloses a process for the restructuring of olefins in contact with zeolite catalyst to produce iso-olefins, followed by the conversion of iso-olefins to MTBE and TAME. The restructuring conditions comprise temperatures between 204°C and 315°C and pressure below 51 kPa.

10 In EP-A-247802, it is taught that linear olefins can be restructured in contact with zeolite catalyst, including Theta-1 (ZSM-22) and ZSM-23, to produce branched olefins. The restructuring conditions comprise temperature between 200-550°C, pressure between 100 and 5000 kPa and WHSV between 1 and 100. Selectivities to isobutene up to 91.2% are reported using a calcined Theta-1 tectometallosilicate at 400°C and 30.6% 1-butene conversion.

15 U.S. Patent 3,992,466 teaches the use of ZSM-35 as a catalyst for hydrocarbon conversion reactions, including "isomerization of aromatics, paraffins and olefins."

20 U.S. Patent 4,922,048 discloses the use of a wide variety of medium pore size zeolites, e.g. ZSM-5, ZSM-11, ZSM-12, ZSM-22, ZSM-23, ZSM-35 and ZSM-48, in low temperature (232-385°C) olefin interconversion of C₂-C₆ olefins to products including tertiary C₄-C₅ olefins and olefinic gasoline.

25 U.S. Patent 4,886,925 discloses low pressure, high temperature conversion of light olefins to produce higher olefins rich in isoalkenes. The process converts C₂₊ n-alkenes to a product comprising C₄-C₆ alkenes rich in iso-alkenes, C₇₊ olefinic gasoline boiling range hydrocarbons, and unconverted hydrocarbons over ZSM-5. The reference teaches further treatment of the alkene effluent with methanol.

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in the presence of medium pore size zeolites such as ZSM-5, ZSM-11, ZSM-12, ZSM-35, ZSM-38 and ZSM-48.

U.S. Patent 4,996,386 discloses concurrent isomerization and disproportionation of olefins using
5 a ferrierite/Mo/W/Al₂O₃ catalyst. The catalyst exemplified produces fewer branched olefins than a comparable material free of ferrierite and the reference teaches that ferrierite-containing catalysts exhibit improved selectivity to linear olefins than
10 conventionally prepared disproportionation catalysts.

Despite the efforts exemplified in the above references, the skeletal isomerization of olefins, e.g., to produce isobutene, has been hampered by relatively low selectivity to isobutene perhaps owing
15 to the reactivity of these olefins. It is further known that skeletal isomerization becomes more difficult as hydrocarbons of lower molecular weight are used, requiring more severe operating conditions, e.g. higher temperatures and lower linear olefin
20 partial pressures.

Generally, the conversion of n-butenes to iso-butene is conducted at selectivities below 90%. In order to obtain higher selectivities, operation at high temperatures (>500°C) and with high nitrogen feed
25 dilution (butene partial pressure, typically less than 5 psia (34.5 kPa)) is generally required. Selectivities of greater than 90%, 95% or even 99% are highly advantageous in commercial conversion of n-butenes to isobutene in order to avoid the need to
30 separate out materials other than n-butene from the product stream. Such high selectivities will permit direct introduction (cascading) or indirect introduction of the isomerizer effluent to an etherification zone where isobutene is reacted with
35 alkanol to produce alkyl tert-butyl ether, e.g. MTBE.

Unconverted n-butenes in the isomerizer effluent can be withdrawn either before the etherification zone or preferably, from the etherification zone effluent insofar as the etherification reaction utilizes only the isobutene component of the isomerizer stream. Unreacted n-butenes from the etherification zone effluent can be recycled to the isomerizer where they are converted to isobutene at high selectivity. If the recycle stream contains not only unconverted linear olefins, e.g. n-butenes, but also by-product such as other olefins (e.g. propylene) or paraffins, they have to be removed from the recycle stream, such as by distillation or by taking a slip stream. These removal steps are expensive and can lead to considerable loss of not only the by-products but butenes as well. These losses are larger when the by-products formed are present in higher concentration. Thus, even small improvements in the isobutene selectivity during n-butene isomerization have a major effect on the commercial viability of the process. However, high selectivities in skeletal isomerization processes have generally required low linear olefin partial pressures and high temperatures which place substantial limitations on such processes. It would, therefore, be advantageous to provide a skeletal isomerization catalyst capable of maintaining relatively high selectivity at low temperatures and high linear olefin partial pressures.

Certain zeolites have been shown to be highly effective in skeletal isomerization of normal olefins. Such zeolites include those selected from the group consisting of zeolites having the framework structure of ZSM-22, ZSM-23, and ZSM-35.

Although such catalyst compositions exhibit adequate thermal stability and cycle length, improving

such properties would be economically advantageous by extending catalyst life and reactor down time.

Accordingly, the present invention provides a process for conversion of linear olefins to
5 corresponding iso-olefins of the same carbon number which comprises contacting a linear olefin-containing organic feedstock with a catalyst comprising a zeolite which has a Constraint Index of 1-12 and which has
10 been treated with a dicarboxylic acid under conditions sufficient to effect a significant reduction in surface acidity of the zeolite as determined by tri-tertiarybutylbenzene conversion.

The dicarboxylic acid treatment of the present invention is found to selectively deactivate the
15 surface acidity of the zeolite without substantially reducing the alpha value (as hereinafter described) or overall activity of the zeolite, which in turn is found to result in reduced catalyst aging and longer cycle length.

20 The skeletal isomerization reaction of the present invention is preferably carried out at a temperature between 100 and 750°C; weight hourly space velocity based on linear olefin in the feed between 0.1 and 500 WHSV; and linear olefin partial pressure
25 between 2 and 2000 kPa. The preferred conditions are a temperature between 200 and 600°C, more preferably between 250 and 550°C, WHSV between 1 and 400, more preferably between 5 and 100; and a linear olefin partial pressure between 10 and 500 kPa, more
30 preferably between 2 and 200 kPa. Under these conditions the conversion of linear olefin, e.g., n-butene, can be at least 10%, preferably at least 25% and more preferably at least 35%. Generally, economically feasible isomerization is maintained at

n-olefin conversion levels above 25 wt%, preferably above 30 wt%.

5 The present invention is especially suited to processes carried out at high linear olefin to iso-olefin selectivity, e.g, at least 75% at
10 relatively low conversion temperatures and high linear olefin partial pressures. Such processes can maintain selectivities of at least 90, 92 or 95% at a conversion temperature less than or equal to 550, 400 or even 350°C, and linear olefin partial pressures above 2 psia (14 kPa), e.g above 5 psia (34 kPa). Zeolites used in these processes treated with dicarboxylic acid exhibit maintain substantially equivalent overall catalytic activity as measured by
15 alpha value. However, the treated zeolites retain their operable activity (permitting overall n-olefin conversion of at least 30%) for a significantly longer period, representing a reduction in aging rate of at least 25%, preferably at least 40% or even 50%.

20 Preferred feedstreams include C_4 or C_4+ hydrocarbon feedstreams. Linear olefins suited to use in the present invention may be derived from a fresh feedstream, preferably comprising n-butenes and/or n-pentenenes, or from the effluent of an iso-olefin
25 etherification reactor which employs alkanol and C_4 or C_4+ hydrocarbon feedstock. Typical hydrocarbon feedstock materials for isomerization reactions according to the present invention include olefinic streams, such as cracking process light gas containing
30 butene isomers in mixture with substantial amounts of paraffins including n-butane and isobutane. The C_4 components usually contain a major amount of unsaturated compounds, such as 10-40% isobutene, 20-55% linear butenes, and small amounts of butadiene. Also,
35 C_4+ heavier olefinic hydrocarbon streams may be used,

e.g., C₄ to C₁₀, preferably C₄ to C₆ olefinic hydrocarbon streams.

The zeolites useful in the process of the invention have a silica to alumina molar ratio of at least 12 and a Constraint Index of 1-12. Constraint Index is described in US Patent No. 4016218 and the Constraint Index of some typical zeolites are listed below:

		<u>Constraint Index</u>
10	ZSM-4	0.5
	ZSM-5	8.3
	ZSM-11	8.7
	ZSM-12	2
	ZSM-23	9.1
15	ZSM-35	4.5
	ZSM-38	2
	TMA Offretite	3.7
	Beta	0.6 - 2
	H-Zeolon (mordenite)	0.4
20	REY	0.4
	Amorphous Silica-Alumina	0.6
	Erionite	38

Within the above group of zeolites having a Constraint Index of 1-12 is a preferred group of zeolites for the purposes of the present invention. These preferred zeolites, exemplified by ZSM-22, ZSM-23, and ZSM-35, have channels described by 10-membered rings of T (=Si or Al) or oxygen atoms, but differ from other intermediate pore 10-ring zeolites, such as ZSM-5, ZSM-11, ZSM-57 or stilbite, in having a smaller 10-ring channel. If the crystal structure (and hence pore system) of a particular zeolite is known, a convenient measure of the channel cross-section is given by the product of the

5 dimensions (in angstrom units) of the two major axes of the pores. These dimensions are listed in the "Atlas of Zeolite Structure Types" by W. M. Meier and D. H. Olson, Butterworths, publisher, Second Edition, 1987. The values of this product, termed the Pore Size Index, are listed in Table A.

TABLE A
Pore Size Index

	<u>Type</u>	<u>Largest Ring Size</u>	<u>Zeolite</u>	<u>Axes of Largest Channel, A</u>	<u>Pore Size Index</u>
5	1	8	Chabazite	3.8 x 3.8	14.4
			Erionite	3.6 x 5.1	18.4
			Linde A	4.1 x 4.1	16.8
	2	10	ZSM-22	4.4 x 5.5	24.2
			ZSM-23	4.5 x 5.2	23.4
10			ZSM-35	4.2 x 5.4	22.7
			ALPO-11	3.9 x 6.3	24.6
	3	10	ZSM-5	5.3 x 5.6	29.1
			ZSM-11	5.3 x 5.4	28.6
			Stilbite	4.9 x 6.1	29.9
15			ZSM-57 (10)	5.1 x 5.8	29.6
	4	12	ZSM-12	5.5 x 5.9	32.4
			Mordenite	6.5 x 7.0	45.5
			Beta (C-56)	6.2 x 7.7	47.7
			Linde-L	7.1 x 7.1	50.4
20			Mazzite (ZSM-4)	7.4 x 7.4	54.8
			ALPO ₄ -5	7.3 x 7.3	53.3

It can be seen that small pore, eight-ring zeolites have a Pore Size Index below about 20, the intermediate pore, 10-ring zeolites of about 20-31, and large pore, 12-ring zeolites above about 31. It is also apparent, that the 10-ring zeolites are grouped in two distinct classes; Type 2 with a Pore Size Index between 20 and 26 and Type 3 with a Pore Size Index between 28 and 31.

The zeolites preferred for use in this invention are those of Type 2 with a Pore Size Index of 20-26. The Type 2 zeolites are distinguished from the other types by their sorption characteristics towards 3-methylpentane. Representative equilibrium sorption data and experimental conditions are listed in Table B.

Type 2 zeolites sorb in their intracrystalline voids 10 to 40 mg of 3-methylpentane per gram dry zeolite in the hydrogen form at 90°C and 12 kPa (90 torr) 3-methylpentane pressure. In contrast, Type 3 zeolites sorb greater than 40 mg 3-methylpentane under the conditions specified.

The equilibrium sorption values are obtained most conveniently in a thermogravimetric balance by passing a stream of inert gas such as helium containing the hydrocarbon with the indicated partial pressure over the dried zeolite sample held at 90°C for a time sufficient to obtain a constant weight.

Samples containing cations such as sodium or aluminum ions can be converted to the hydrogen form by well-known methods such as exchange at temperatures between 25° and 100°C with dilute mineral acids, or with hot ammonium chloride solutions followed by calcination. For mixtures of zeolites with amorphous material or for poorly crystallized samples, the sorption values apply only to the crystalline portion.

This method of characterizing the Type 2 zeolites has the advantage that it can be applied to zeolites whose crystal structure has not yet been determined.

TABLE B

Equilibrium Sorption Data of Medium Pore Zeolites

Type	Zeolite	<u>Amount sorbed, mg per g zeolite</u>	
		<u>3-Methylpentane^{a)}</u>	
2	ZSM-22	20	
	ZSM-23	25	
	ZSM-35	25	
3	ZSM-5	61	
	ZSM-12	58	
	ZSM-57	70	
	MCM-22	79	

a) at 90°C, 90 torr 3-methylpentane

ZSM-22 is more particularly described in U.S. Patent No. 4,556,477. ZSM-22 and its preparation in microcrystalline form using ethylpyridinium as directing agent is described in U.S. Patent No. 4,481,177. For purposes of the present invention, ZSM-22 is considered to include its isotypes, e.g., Theta-1, Gallo-Theta-1, NU-10, ISI-1, and KZ-2.

ZSM-23 is more particularly described in U.S. Patent No. 4,076,842. For purposes of the present invention, ZSM-23 is considered to include its isotypes, e.g., EU-13, ISI-4, and KZ-1.

ZSM-35 is more particularly described in U.S. Patent No. 4,016,245. For purposes of the present invention, ZSM-35 is considered to include its isotypes, e.g., ferrierite, FU-9, ISI-6, NU-23, and Sr-D. An example of a piperidine-derived ferrierite

is more particularly described in U.S. Patent No. 4,343,692. Other synthetic ferrierite preparations are described in U.S. Patent Nos. 3,933,974; 3,966,883; 4,000,248; 4,017,590; and 4,251,499.

5 Further descriptions of ferrierite are found in Bibby et al, "Composition and Catalytic Properties of Synthetic Ferrierite," Journal of Catalysis, 35, pages 256-272 (1974).

10 The zeolite catalyst used is preferably at least partly in the hydrogen form, e.g., HZSM-22, HZSM-23, or HZSM-35. Other metals or cations thereof, e.g. rare earth cations, may also be present. When the zeolites are prepared in the presence of organic cations, they may be quite inactive possibly because
15 the intracrystalline free space is occupied by the organic cations from the forming solution. The zeolite may be activated by heating in an inert or oxidative atmosphere to remove the organic cations, e.g. by heating at over 500°C for 1 hour or more. The
20 hydrogen form can then be obtained by base exchange with ammonium salts followed by calcination, e.g., at 500°C in air. Other cations, e.g. metal cations, can be introduced by conventional base exchange or impregnation techniques.

25 In order to obtain desired linear olefin skeletal isomerization activity/selectivity, the zeolite, preferably in the hydrogen form, should have an alpha value of at least 1, preferably at least 10 when used in the catalyst of the present invention. Alpha
30 value, or alpha number, of a zeolite is a measure of zeolite acidic functionality and is more fully described together with details of its measurement in U.S. Patent No. 4,016,218, J. Catalysis, 6, pp. 278-287 (1966) and J. Catalysis, 61, pp. 390-396
35 (1980). The experimental conditions cited in the

latter reference are used for characterizing the catalysts described herein.

5 Prior to use in the skeletal isomerization process of the present invention, the zeolite is treated with a dicarboxylic acid under conditions to effect a reduction, typically of 20, 40 or even 50%, of its surface activity. The treatment with dicarboxylic acid is believed to remove aluminum from the crystal surface of the zeolite and thereby reduce the surface activity.

10 Suitable dicarboxylic acids for use in the surface treatment include oxalic, malonic, succinic, glutaric, adipic, citric, tartaric, maleic, phthalic, isophthalic, terephthalic, and fumaric acid or mixtures thereof, with oxalic acid being preferred.

15 The dicarboxylic acid may be used in solution, such as an aqueous dicarboxylic acid solution. Generally, the acid solution has a concentration of 0.01 to 4 M, more preferably 1 to 3 M.

20 The dicarboxylic acid is generally in a volume solution to volume catalyst ratio of at least 1:1, preferably at least 4:1.

Treatment time with the dicarboxylic acid solution is as long as required to provide the desired reduction in surface acidity. Generally the treatment time is at least 10 minutes, more preferably at least 1 hour. The treatment temperature is generally 0°C (32°F) to reflux, preferably 15°C to 93°C (60°F to 200°F), and more preferably 49°C to 82°C (120°F to 180°F).

30 More than one dicarboxylic acid treatment step may be employed in the process of the present invention for enhanced deactivation of surface acidity.

The surface acidity of a zeolite can be determined by conversion of tri-tertiarybutylbenzene (TTBB), a bulky molecule that can only react with the acid sites on the zeolite crystal surface.

5 Dealkylation of TTBB is a facile, reproducible method for measuring surface acidity of catalysts. External surface acidity can be measured exclusive of internal activity for zeolites with pore diameters up to and including faujasite. As a test reaction, dealkylation
10 of TTBB occurs at a constant temperature in the range 25 to 300°C and preferably in the range 200 to 260°C.

The experimental conditions for the test used herein include a temperature of 200°C and atmospheric pressure. The dealkylation of TTBB is carried out in
15 a glass reactor (18 cm x 1 cm OD) containing an 8 g 14/30 VycorTM chip preheater followed by 0.1 g catalyst powder mixed with VycorTM chips. The reactor is heated to 200°C in 30 cc/g nitrogen for 30 minutes to remove impurities from the catalyst sample. Ten
20 g/hr of TTBB dissolved in toluene (7% TTBB) is injected into the reactor. The feed vaporizes as it passes through the preheater and passes over the catalyst sample as vapor. After equilibrium is reached the nitrogen is switched to 20 cc/min
25 hydrogen. The test is then run for 30 minutes with the reaction products in a cold trap.

The reaction products are analyzed by gas chromatography. The major dealkylation product is di-t-butylbenzene (DTBB). Further dealkylation to
30 t-butylbenzene (TBB) and benzene (B) occurs but to a lesser extent.

Conversion of TTBB is calculated on a molar carbon basis. Dealkylation product weight %s are each multiplied by the appropriate carbon number ratio to
35 convert to the equivalent amount of TTBB, i.e. DTBB x

18/14, TBB x 18/10 and B x 18/6. These values are then used in the following conversion equation where asterisks indicate adjustment to the equivalents.

$$\begin{array}{l} \text{DTBB}^* + \text{TBB}^* + \text{B}^* \\ 5 \quad \% \text{ Conversion} = \frac{\quad}{\text{TTBB} + \text{DTBB}^* + \text{TBB}^* + \text{B}^*} \times 100 \end{array}$$

In addition, thermal background experiments using reactors filled with VycorTM chips only show no TTBB conversion due to VycorTM or other reactor components.

10 Preferably, the dicarboxylic acid treatment is conducted so as to result in a reduction in surface acidity of at least 20%, preferably at least 40%, more preferably at least 50%, as measured by tri-tertiary-butylbenzene conversion, without a significant
15 reduction in overall activity as measured by alpha test. By significant reduction in overall activity is meant a reduction in alpha value of not greater than 20%.

20 The dicarboxylic acid treatment of this invention may also be combined with other conventional dealumination techniques, such as steaming and chemical treatment.

Prior to or following contact with dicarboxylic acid, the zeolite may be composited with a porous
25 matrix material, such as alumina, silica, titania, zirconia, silica-alumina, silica-magnesia, silica-zirconia, silica-thoria, silica-beryllia, silica-titania as well as ternary compositions, such as silica-alumina-thoria, silica-alumina-zirconia,
30 silica-alumina-magnesia, and silica-magnesia-zirconia. The matrix may be in the form of a cogel. The relative proportions of zeolite component and inorganic oxide gel matrix may vary widely with the zeolite content ranging from between 1 to 99, more
35 usually 5 to 80, percent by weight of the composite.

The regeneration of spent zeolite catalyst used in the isomerization reaction is carried out oxidatively or hydrogenatively employing procedures known in the art. The catalyst of the present invention can be readily reactivated without significantly reducing selectivity for iso-olefin by exposing it to hydrogen for a suitable period, e.g. overnight.

The invention will now be more particularly with reference to the following examples and the accompanying drawing which is a graph comparing the catalyst aging for oxalic acid treated and untreated silica bound ZSM-35 when used in an n-olefin skeletal isomerization process according to one example of the present invention..

EXAMPLE 1

Preparation of As-Synthesized ZSM-35

1.18 parts of aluminum sulfate (17.2% Al_2O_3) were added to a solution containing 9.42 parts H_2O and 1.38 parts of 50% NaOH solution in an autoclave. 0.03 parts of ZSM-35 seeds and 3.20 parts of Hi-Sil precipitated silica were added with agitation, followed by 1.0 part of pyrrolidine.

The reaction mixture had the following composition, in mole ratios:

$\text{SiO}_2/\text{Al}_2\text{O}_3$	21.5
OH^-/SiO_2	0.11
$\text{H}_2\text{O}/\text{Al}_2\text{O}_3$	13.5
$\text{R}/\text{Al}_2\text{O}_3$	6.45

where R = pyrrolidine. The mixture was crystallized at 105°C for 74 hours with stirring. The ZSM-35 product was filtered, washed with deionized water, and dried at 120°C.

The chemical composition of the product was, in weight percent:

	SiO ₂	76.7
	Al ₂ O ₃	6.4
5	Na	0.84
	C	7.26
	N	2.03
	Ash @ 1000°C	85.5

10 with a silica/alumina ratio for the product, in moles, of 20.3/1.

EXAMPLE 2

Preparation of Silica-Bound HZSM-35

A catalyst was prepared by dry mixing 65 parts of the as-synthesized ZSM-35 of Example 1 with 35 parts
15 of precipitated silica, in proportion to give, after calcination, 65% ZSM-35 / 35% silica in the catalyst. A solution containing 2% NaOH (based on solids) was added to the mix to create an extrudable mull, the mix was extruded to 1/16 inch (1.6 mm) diameter and dried
20 at 120°C. The extrudate was exchanged two times with 1N NH₄NO₃ solution at room temperature, rinsed with deionized water, dried at 120°C and calcined in nitrogen for 3 hours at 538°C. It was again exchanged with 1N NH₄NO₃ solution two times at room temperature,
25 dried at 120°C, and calcined in air for 9 hours at 538°C.

The resulting catalyst had an alpha activity (measured using n-hexane conversion) of 102 and a surface acidity (measured using tri-tertiary-
30 butylbenzene conversion) of 18.

Example 3

Oxalic Acid Treated ZSM-35

5 A catalyst was prepared by treating a portion of
the catalyst of Example 2 with 2 M oxalic acid at 71°C
for one hour. The treated sample was washed with
water, dried at 150°C, and calcined at 375°C for 3
hours. The resulting oxalic acid treated catalyst
exhibited an alpha value (activity) of 92 and a
surface acidity of 10. The 10% change in alpha
10 activity from the untreated to treated catalyst is
well within the accuracy of the alpha test. However,
the 45% reduction in surface acidity represents a
significant decrease.

Example 4

15 **Preparation of ZSM-23**

ZSM-23 was prepared by charging 85.5 parts water
to an autoclave followed by 2.64 parts KOH solution
(45% by weight), 1.0 part aluminum sulfate (17.2%
 Al_2O_3) and 0.5 parts ZSM-23 seeds (100% basis). After
20 mixing thoroughly, 14.5 parts of Ultrasil VN3
precipitated silica (Nasilco), then 5.1 parts of
pyrrolidine were added and mixed thoroughly. The
autoclave was heated to 160°C with stirring and
maintained at these conditions until crystallization
25 was complete. The product was identified as ZSM-23 by
X-ray diffraction. After flashing the pyrrolidine,
the slurry was cooled, washed, filtered and dried. 65
parts of the dried ZSM-23 were combined with 35 parts
of SiO_2 (Hi-Sil, a product of PPG Industries Chemical
30 Division, dry milled and extruded to form 1/16 inch
pellets which were dried at 120°C. The pellets were
then calcined in flowing nitrogen for 2 hours at 538°C
and 3 hours in air at the same temperature. The
cooled catalyst was exchanged with 1 N NH_4NO_3 (5 cc/g
35 catalyst) at room temperature for one hour then washed

with water. The exchange procedure was repeated and the catalyst dried at 120°C. The exchanged extrudate was then calcined at 538°C in flowing air for 3 hours. The resulting catalyst exhibited an alpha activity of 27 and a surface acidity of 3.

Example 5

A sample of ZSM-23 from Example 4 was treated with 2 M oxalic acid at 71°C for one hour. The treated sample was washed with water, dried at 150°C for 8 hours, and calcined at 375°C for 3 hours. The resulting catalyst had an alpha value of 33 and a surface acidity of 1.5. While the difference in alpha value is within the accuracy of the alpha test, the 50% reduction in surface acidity represents a significant decrease.

Example 6

Isomerization of 1-Butene with ZSM-35 at 400°C

The catalysts of Examples 2 and 3 were sized to 14/24 mesh and used in butene skeletal isomerization reactions. The approximate experimental conditions were:

Temperature	400°C
Pressure	207 kPa
1-Butene WHSV	33 hr ⁻¹
	(based on active component)
N ₂ /Butene in feed	1 vol/vol

The Figure graphically depicts the respective conversions and isobutene yields obtained for treated and untreated ZSM-35. Isobutene yield from the untreated catalyst dropped from more than 40% to less than 30% in less than 11 days. However, the same drop in yield with the treated catalyst took over 16 days, representing a 40 to 50% reduction in aging rate.

CLAIMS:

1. A process for conversion of linear olefins to corresponding iso-olefins of the same carbon number which comprises contacting a linear
5 olefin-containing organic feedstock with a catalyst comprising a zeolite which has been treated with a dicarboxylic acid under conditions sufficient to effect a significant reduction in surface acidity of the zeolite as determined by
10 tri-tertiarybutylbenzene conversion without substantially reducing the overall activity of the zeolite as indicated by alpha value.
2. The process of claim 1 wherein the zeolite sorbs
15 10 to 40 mg 3-methylpentane at 90°C and 12 kPa (90 torr) per gram of the dry zeolite in the hydrogen form.
3. The process of claim 1 wherein said zeolite is selected from ZSM-22, ZSM-23, and ZSM-35.
4. The process of claim 1 wherein said dicarboxylic
20 acid is selected from oxalic, malonic, succinic, glutaric, adipic, maleic, phthalic, isophthalic, terephthalic, fumaric, tartaric acid and mixtures thereof.
5. The process of claim 4 wherein said dicarboxylic
25 acid is oxalic acid.
6. The process of claim 1 wherein treatment with the dicarboxylic acid is effected for a time of at least 10 minutes at a temperature of 15°C to 93°C (60°F to 200°F).



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7. The process of claim 1 wherein treatment with the dicarboxylic acid is effected so as to reduce the surface acidity of the zeolite as determined by tri-tertiarybutylbenzene conversion by at least 20%.
- 5 8. The process of claim 1 wherein said contacting is carried out at a temperature of 100 to 750°C, a weight hourly space velocity based on linear olefins in said feedstock between 0.1 and 500 WHSV, and a linear olefin partial pressure of 2
10 to 2000 kPa.
9. The process of claim 1 wherein said contacting is carried out at a temperature of 200 to 600°C, a weight hourly space velocity based on linear olefins in said feedstock between 1 and 400 WHSV,
15 and a linear olefin partial pressure of 10 to 500 kPa.
10. The process of claim 1 wherein said feedstock comprises C₄ to C₁₀ linear olefins.

