



(12) PATENT ABRIDGMENT **(11) Document No. AU-B-10091/92**
(19) AUSTRALIAN PATENT OFFICE **(10) Acceptance No. 645167**

- (54) Title
ACTIVATED ZEOLITE BETA CATALYST AND ISOMERIZATION PROCESS THEREFOR
- International Patent Classification(s)
(51)⁵ **B01J 029/28 B01J 037/14 C10G 035/095**
- (21) Application No. : **10091/92** (22) Application Date : **08.01.92**
- (43) Publication Date : **15.07.93**
- (44) Publication Date of Accepted Application : **06.01.94**
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- (56) Prior Art Documents
WO 90/13364
US 4554065
US 3308069

(57) Claim

1. A process for isomerizing normal paraffin hydrocarbons to form non-normal paraffin hydrocarbons comprising the steps of:

(a) heating an initial zeolite beta catalyst in air or an inert atmosphere at an initial temperature of less than 540°C effective to form an initial concentration of weak acid species and strong acid species and continuing said heating at an activation temperature of from 600° to 700°C effective to substantially reduce or to substantially eliminate the concentration of strong acid species without substantially reducing the concentration of weak acid species to form an activated zeolite beta catalyst;

(b) passing a feedstock comprising said normal paraffin hydrocarbons and hydrogen to an isomerization zone containing said activated catalyst at an isomerization temperature at least 300°C lower than said activation temperature and effective to convert at least a portion of said normal paraffin hydrocarbons into said non-normal paraffin hydrocarbons; and

(c) withdrawing a product stream comprising said non-normal paraffin hydrocarbons.

**"ACTIVATED ZEOLITE BETA CATALYST
AND ISOMERIZATION PROCESS THEREFOR"**

FIELD OF THE INVENTION

This invention relates to normal paraffin isomerization processes and to
5 methods for enhancing at least one catalytic property of a crystalline microporous
three-dimensional solid catalyst having the structure and composition of zeolite beta
for use in such normal paraffin isomerization processes.

BACKGROUND OF THE INVENTION

A wide variety of hydrocarbon conversion processes encountered in the
10 petroleum refining industry are catalytic in nature and many of these processes use
crystalline aluminosilicate zeolites as catalysts. Illustrative of such processes include,
for example, dewaxing, hydrodewaxing, cracking, hydrocracking, alkylation,
isomerization, aromatization, disproportionation and the like. Often, the products
from such hydrocarbon conversion processes, or portions thereof, are admixed as
15 blending components to form motor fuels such as gasoline.

The isomerization of low molecular weight normal paraffin hydrocarbons to
non-normal paraffin hydrocarbons is a well known hydrocarbon conversion process
and is described in various patents, for example, U.S. Patent Nos. 4,210,771 and
3,150,205. This reaction is of importance in the petroleum industry because of the
20 higher octane number of isoparaffin hydrocarbons compared to their normal paraffin
hydrocarbon counterparts. Since gasoline blends require a distribution of boiling
range materials, the isoparaffins in the C₄-C₇ range are valuable blending
components which have a higher octane number than a corresponding gasoline
fraction consisting of normal paraffins. A variety of catalysts have been prepared to
25 catalyze the isomerization. For instance, Friedel-Crafts catalysts, such as aluminum
chloride, are known to be isomerization catalysts. Halogenated catalysts, such as
platinum supported on halogenated alumina support have also been used to isomerize
hydrocarbons. In addition, crystalline aluminosilicate zeolites have been used in the
isomerization of hydrocarbons. Both natural and synthetic crystalline aluminosilicates
30 have been employed. Typically, the zeolites comprise a noble metal such as platinum
or palladium. Included among these are the Type X and Type Y zeolites, ZSM-5 and
ZSM-20 zeolites, mordenite, as well as zeolite beta.

U.S. Patent No. 3,308,069 discloses a method for preparing zeolite beta. The patents disclose that zeolite beta is prepared from reaction mixtures containing tetraethylammonium hydroxide as the alkali and more specifically by heating in aqueous solution a mixture of the oxides or of materials whose chemical compositions
5 can be completely represented as mixtures of the oxides Na_2O , Al_2O_3 , $[(\text{C}_2\text{H}_5)_4\text{N}]_2\text{O}$, SiO_2 and H_2O suitably at a temperature of about $75\text{-}200^\circ\text{C}$ until crystallization occurs. The product which crystallizes from the hot reaction mixture is separated, suitably by centrifuging or filtration, washed with water and dried. The material so obtained may be calcined by heating in air or an inert atmosphere at a
10 temperature in the approximate range of $400\text{-}1700^\circ\text{F}$ or higher so long as the temperature is not sufficient to destroy the crystallinity.

U.S. Patent No. 4,642,226 relates to a new and improved form of crystalline silicate having the structure of zeolite beta, to a new and useful improvement in synthesizing said crystalline silicate and to the use of said crystalline silicate as a
15 catalyst for organic compound, e.g., hydrocarbon compound, conversion. The patent discloses the use of dibenzyl-dimethyl-ammonium as a directing agent, i.e., templating agent, instead of tetraethyl-ammonium hydroxide as described above. The patent further discloses that the zeolite beta can be ion-exchanged by conventional techniques with a salt solution. Following contact with the salt solution of the desired
20 replacing cation, the zeolite is then preferably washed with water and dried at a temperature ranging from 65 to about 315°C and thereafter may be calcined in air or other inert gas at temperatures ranging from about 200 to about 600°C , preferably from about 200 to about 550°C for periods of time ranging from 1 to 48 hours or more to produce a catalytically active thermal decomposition product thereof. The patent
25 discloses the use of zeolite beta in hydroisomerization of normal paraffins, when provided with a hydrogenation component, e.g., platinum.

It can be seen from the disclosures of the above cited prior art that zeolite beta has been prepared for use as a catalyst in normal paraffin isomerization processes. Accordingly, processes are sought for enhancing at least one catalytic
30 property of zeolite beta, preferably catalytic activity and selectivity, for use in normal paraffin isomerization processes.

SUMMARY OF THE INVENTION

The present invention relates to processes for isomerizing normal paraffin hydrocarbons using a crystalline microporous three-dimensional solid catalyst having the structure and composition of zeolite beta wherein at least one catalytic property, i.e., catalytic activity or selectivity, is enhanced. In accordance with the present invention, the isomerization reaction is performed using a zeolite beta catalyst that has been activated by heating in air or an inert atmosphere at a temperature effective to substantially reduce, and preferably eliminate, the concentration of strong acid species without substantially reducing the concentration of weak acid species, both the strong acid and weak acid species being initially present on the catalyst.

According to the invention there is provided a process for isomerizing normal paraffin hydrocarbons to form non-normal paraffin hydrocarbons in the presence of an activated zeolite beta catalyst, the process comprising the steps of: (a) heating an initial zeolite beta catalyst in air or an inert atmosphere at an initial temperature of less than 450°C effective to form an initial concentration of weak acid species and strong acid species and continuing said heating at an activation temperature of from 600° to 700°C effective to substantially reduce or to substantially eliminate the concentration of strong acid species without substantially reducing the concentration of weak acid species to form the activated zeolite beta catalyst; (b) passing a feedstock comprising said normal paraffin hydrocarbons and hydrogen to an isomerization zone containing said activated catalyst at an isomerization temperature at least 300°C lower than said activation temperature and effective to convert at least a portion of said normal paraffin hydrocarbons into said non-normal paraffin hydrocarbons; and (c) withdrawing a product stream comprising said non-normal paraffin hydrocarbons.



reaction mixture expressed in terms of mole ratios, preferably falls within the following ranges:

$\text{SiO}_2/\text{Al}_2\text{O}_3$ - 10 to 200;

Na_2O /tetraethylammonium hydroxide (TEAOH) - 0.0 to 0.1;

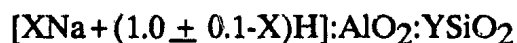
5 TEAOH/ SiO_2 - 0.1 to 1.0; and

H_2O /TEAOH - 20 to 75.

The product which crystallizes from the hot reaction mixture is separated, suitably by centrifuging or filtration, washed with water and dried.

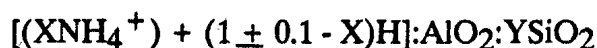
The material so obtained should then be calcined by heating preferably in
 10 air or an inert atmosphere at a temperature usually within the range of from 200 to 1000°C or higher, preferably from 550 to 750°C, more preferably from 75 to about 675°C, and most preferably from 600 to 650°C, and for a period of time preferably in excess of 0.25 hours, more preferably in excess of 0.50 hours. The calcination should preferably not cause degradation of any catalytic sites in zeolite beta. This calcination
 15 oxidizes and/or decomposes at least a substantial portion of the catalyst templating agent, e.g., tetraethylammonium ions or dibenzyltrimethylammonium ions when used instead, or in addition to TEA, from the catalyst templating agent, to hydrogen ions and removes the water to provide a zeolite beta that is substantially freed of templating agent. The calcined zeolite beta is also known as H-form zeolite beta. As
 20 used herein, the terms "at least a substantial portion" and "substantially freed" refer to at least 50 wt.%, preferably at least 75 wt.% and most preferably 100 wt.% oxidation and/or decomposition of the catalyst templating agent from the as-synthesized zeolite beta.

With 100 wt.% oxidation and/or decomposition of the catalyst templating
 25 agent, the formula of zeolite beta can then be depicted as follows:



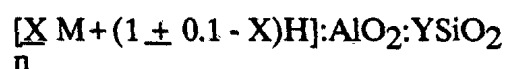
where X and Y are as defined above. The degree of hydration is considered to be zero following the calcination.

The H-form zeolite beta is then preferably ion-exchanged with a salt solution containing at least one hydrogen-forming cation other than hydronium, such as NH_4^+ or quaternary ammonium, in which sodium is replaced by the hydrogen-forming cation to give zeolite beta of the formula (anhydrous basis with NH_4^+ exchange):



where X and Y are as defined above.

According to this invention, the hydrogen-forming cation-exchanged form of zeolite beta may optionally be subjected to metal cation-exchange to give a material of the formula (anhydrous basis):



where X and Y are as described above and n is the valence of the metal M which may be any metal.

According to this invention, the hydrogen-forming cation-exchange form of zeolite beta or the metal cation-exchange form of zeolite beta can preferably be combined with at least one inorganic oxide matrix component and thereafter activated by heating in air or an inert atmosphere at a temperature and for a period of time sufficient to enhance at least one catalytic property of the catalyst in a hydrocarbon isomerization process as described hereinafter. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio of zeolite beta product employed in this invention will generally be in the range of from 15:1 to 45:1, preferably from 20:1 to 30:1; and more preferably from 22:1 to 26:1.

Because a templating agent such as tetraethylammonium hydroxide is used in its preparation, zeolite beta may contain occluded tetraethylammonium ions, e.g., as the hydroxide or silicate, within its pores in addition to that required by electroneutrality and indicated in the calculated formulae herein. The formulae are calculated using one equivalent of cation per aluminum atom in tetrahedral coordination in the crystal lattice.

Zeolite beta, in addition to possessing a composition as defined above, may also be characterized by its X-ray diffraction data which are set out in U.S. Patent No. 3,308,069.

Zeolite beta is preferably ion-exchanged following calcination to remove the organic template by contacting (with or without the presence of an inorganic oxide matrix component) said zeolite beta with a salt solution of at least one hydrogen-forming cation, such as NH_4^+ or quaternary ammonium. Zeolite beta may optionally
5 be metal cation-exchanged following the hydrogen-forming cation-exchange. Suitable metal cations include cations selected from the group consisting of cations of Group IIA, Group IIIA, Groups IIIB-VIIB, e.g., nickel, cobalt, iron, manganese, copper, platinum, palladium, rhodium and the like including mixtures thereof, and rare earth cations selected from cerium, lanthanum, praseodymium, neodymium, promethium,
10 samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium and mixtures thereof. Of course, the metal cation present as a result of metal cation-exchange should have no substantial adverse effect on the desired hydrocarbon conversion process. As a result of such ion-exchange, the zeolite beta can contain at least one cation, e.g., hydrogen-forming cation and/or metal
15 cation, which is different from the cations initially associated with zeolite beta as a result of its synthesis. The cation(s) present as a result of ion-exchange is preferably present in an effective amount between 0.1 wt.% and 20 wt.%, based on the weight of the starting zeolite beta and is typically present in an effective amount between 0.5 wt.% and 10 wt.%.

20 The ion-exchange is generally carried out by preparing a slurry of the zeolite beta catalyst by adding 5 to 15 volumes of water per volume of catalyst, after which a solution of a selected cation is added. The ion-exchange is generally carried out at room temperature and the resulting solution is then heated to above 50°C and stirred at this temperature for 0.5 to 3 hours. This mixture is then filtered and water
25 washed to remove excess anion present as a result of the solution of the cation salt.

The zeolite beta is typically employed with at least one inorganic oxide matrix component, which combination is preferably formed after ion-exchange and prior to activation. While zeolite beta can be employed with one or more of a wide variety of inorganic oxide matrix components as hereinafter described, it is important
30 that the pore structure of zeolite beta remain open and readily accessible to the feedstock in order to provide effective catalytic activity. Illustrative inorganic oxide matrix components which may be employed in formulating catalysts, include: amorphous catalytic inorganic oxides such as catalytically active silica/aluminas, clays, silicas, aluminas, silica-aluminas, silica-zirconias, silica-magnesias, silica-thorias, silica-

beryllias, silica-alumina-thorias, silica-alumina-zirconias, alumina-borias, alumina-titanias and the like and mixtures thereof. The matrix may be in the form of a sol, hydrogel or gel and is typically an alumina, silica or silica-alumina component such as a conventional silica-alumina catalyst, several types available. The matrix may itself
5 provide a catalytic effect, such as that observed for catalytically active silica/aluminas, or it may be essentially inert. The matrix may act as a "binder" in some instances although in some instances the final catalyst may be spray dried or formed without the need of a binder.

These matrix materials may be prepared as a cogel of silica and alumina or
10 as alumina precipitated on the preformed and preaged hydrogel. Silica may be present as a major matrix component in the solids present in the matrix, e.g., present in an amount between 5 to 40 wt.% and preferably between 10 to 30 wt.%. The silica may also be employed in the form of a cogel comprising 75 wt.% silica and 25 wt.% alumina or comprising 87 wt.% silica and 13 wt.% alumina. The inorganic oxide
15 matrix component will typically be present in the final catalyst in an amount between 0 and 99 wt.%, preferably between 5 and 90 wt.%, based on the total catalyst. It is also within the scope of the instant invention to employ other materials with the zeolite beta in the final catalysts, including clays, carbon monoxide oxidation promoters, etc.

Representative of matrix systems employable herein are disclosed in British
20 Patent Specification No. 1,315,553 and U.S. Patent Nos. 3,446,727 and 4,086,187, hereby incorporated by reference.

The catalysts of the present invention may be employed with a matrix component and this may be a silica or alumina component. The alumina component may comprise discrete particles of various aluminas, e.g., pseudoboehmite. The
25 alumina component may be in the form of discrete particles having a total surface area, as measured by the method of Brunauer, Emmett and Teller (BET), greater than 20 square meters per gram (M^2/g), preferably greater than 145 M^2/g , for example, from 145 to 300 M^2/g . The pore volume of the alumina component will typically be greater than 0.35 cc/g. The average particle size of the alumina particles
30 is generally less than 10 microns and preferably less than 3 microns. The alumina may be employed alone as the matrix or composited with the other matrix components.

The alumina component may be any alumina and has preferably been preformed and placed in a physical form such that its surface area and pore structure are stabilized so that when the alumina is added to an impure, inorganic gel containing considerable amount of residual soluble salts, the salts will not alter the surface and pore characteristics measurably nor will they promote chemical attack on the preformed porous alumina which could undergo change. For example, the alumina is typically an alumina which has been formed by suitable chemical reaction, then slurry aged, filtered, dried, washed free of residual salt and then heated to reduce its volatile content to less than 15 wt.%. The alumina component may be present in the final catalyst in an amount ranging between 5 and 95 wt.%, preferably between 10 and 30 wt.% based on the total catalyst. Further, an alumina hydrosol or hydrogel or hydrous alumina slurry may be used in the catalyst preparation.

Mixtures of zeolite beta and one or more inorganic oxide matrix components may be formed into a final form for the catalyst by standard catalyst forming techniques including spray drying, pelleting, extrusion and other suitable conventional means.

Catalysts containing zeolite beta may be prepared by any conventional method. One method of preparing such catalysts employing silica-alumina and porous alumina is to react sodium silicate with a solution of aluminum sulfate to form a silica/alumina hydrogel slurry which is then aged to give the desired pore properties, filtered to remove a considerable amount of the extraneous and undesired sodium and sulfate ions and then reslurried in water. The alumina may be prepared by reacting solutions of sodium aluminate and aluminum sulfate under suitable conditions, aging the slurry to give the desired pore properties of the alumina, filtering, drying, reslurry in water to remove sodium and sulfate ions and drying to reduce volatile matter content to less than 15 wt.%. The alumina may then be slurried in water and blended in proper amounts, with a slurry of impure silica-alumina hydrogel. The zeolite beta may then be added to this blend. A sufficient amount of each component is utilized to give the desired final composition. The resulting mixture is then filtered to remove a portion of the remaining extraneous soluble salts therefrom. The filtered mixture is then dried to produce dried solids. The dried solids are subsequently reslurried in water and washed substantially free of the undesired soluble salts. The catalyst is then dried with or without heat to a residual water content of less than 15 wt.%. The catalyst is employed after activation as described hereinbelow.

For purposes of the present invention, the zeolite beta catalyst must be activated by heating in air or an inert atmosphere at an initial temperature effective to form an initial concentration of weak acid species and strong acid species and continuing said heating at an activation temperature effective to substantially reduce the concentration of strong acid species without substantially reducing the concentration of weak acid species, both the weak acid and strong acid species being present in the catalyst prior to the activation. Representative of the strong acid species are hydronium cations, i.e., H_3O^+ and representative of the weak acid species are hydroxoaluminum cations, i.e., $\text{Al}(\text{OH})_{3-x}^{\text{x}+}$. It is not critical to the present invention how the concentration of the respective acid species is determined. One suitable procedure is set forth in the following reference; D. W. Breck and G. W. Skeels, ZEOLITE CHEMISTRY I. THE ROLE OF ALUMINUM IN THE THERMAL TREATMENT OF AMMONIUM EXCHANGED ZEOLITE Y, Proceedings of the Sixth International Congress on Catalysis, Vol. 2, pp. 645-659, The Chemical Society, London, (1977). This procedure generally involves treating the zeolite sample in a sodium chloride solution and then titrating the sample with sodium hydroxide to obtain two end points, one at a low pH, i.e., the strong acid, and one at a high pH, i.e., the weak acid. A result in terms of milliequivalents of sodium hydroxide per gram of zeolite can then be obtained for each acid species and translated to acid concentration.

Preferably, the activation temperature is effective to reduce the concentration of hydronium cations after activation to a level corresponding to less than 0.2 milliequivalents of NaOH per gram of zeolite beta. Even more preferably, the activation temperature is effective to substantially eliminate the hydronium cations. It is further preferred that the concentration of hydroxoaluminum cations after activation corresponds to a level of at least 0.8 milliequivalents of NaOH per gram of zeolite beta.

Many of the references hereinbefore cited disclose that the zeolite beta catalyst should be activated at a temperature of 540°C . In accordance with the present invention, it is preferred that the activation temperature be effective to reduce the concentration of strong acid species by at least 50% as compared to the concentration of strong acid species remaining after activating at 540°C . Also, it is preferred in accordance with the present invention that the activation temperature be effective to increase the concentration of weak acid species as compared to the concentration of

weak acid species remaining after activating at 540°C. More preferably, the concentration of weak acid species is increased by at least 20%. In general, the activation temperatures that correspond to the range wherein the concentration of strong acid sites can be substantially reduced without substantially reducing the concentration of weak acid sites is at least 600°C and less than 700°C. Preferably, the activation temperature is from 625-675°C.

The activation time period is not narrowly critical and typically is in excess of 0.25 hours, preferably in excess of 0.50 hours, so long as the activation period is not sufficient to destroy the crystallinity of zeolite beta. Activation of zeolite beta catalyst for a period of 1 hour or longer is a preferred aspect of this invention.

It is important to note that the activation process of the present invention can be performed on a zeolite beta-containing catalyst in any of its stages of existence beyond the as-synthesized stage. That is, the process of the present invention can be performed on zeolite beta in the as-synthesized form, calcined form or in the ion-exchanged form. Moreover, it is to be further understood that the process of the present invention can be used to treat regenerated catalysts as well, e.g., catalysts that have been subjected to oxidative regeneration for carbon removal.

Hence, in one aspect of the present invention, the calcination step can be included in the process, along with ion-exchange and activation steps described above. Thus, the present invention can be practiced on as-synthesized zeolite beta which contains templating agent by including the calcination step in the process.

In another aspect of the present invention, it is not required that the calcination step be performed. For example, a catalyst supplier may provide zeolite beta that has been previously calcined. In such a case, the process would include the ion-exchange step and the activating step as described above.

In still yet another aspect of the present invention, it is not required to perform the ion-exchange step. This would be appropriate when the zeolite beta has already been ion-exchanged as described above and perhaps dried such as when the catalyst is ready for loading in a reactor vessel.

According to a preferred aspect of this invention, a normal/non-normal paraffinic hydrocarbon feedstock is contacted with the activated zeolite beta catalyst in a reaction zone at an isomerization temperature at least 300°C lower than the

activation temperature and effective to convert at least a portion of the normal paraffin hydrocarbons into a non-normal paraffin hydrocarbon product.

The normal paraffin hydrocarbon feedstock to the reactor generally comprises normal paraffins in the C₅ to about C₁₅ carbon atom range and is preferably composed principally of the various isomeric forms of saturated hydrocarbons having from 5 to 6 carbon atoms. Such feedstocks are normally the result of refinery distillation operations, and thus may contain small amounts of C₇ and even higher hydrocarbons, but these are frequently present, if at all, only in trace amounts. Olefinic hydrocarbons are advantageously less than about 4 mol.% in the feedstock. Aromatic and cycloparaffin molecules have a relatively high octane number, but are to a substantial degree cracked and/or converted into molecules of much lower octane number in the isomerization process. Accordingly, the preferred feedstock should not contain more than about 25 mol.% combined aromatic and cycloparaffinic hydrocarbons. Advantageously, the C₅ and C₆ non-cyclic paraffins comprise at least 75 mol.% of the feedstock, with at least 25 mol.% being normal pentane and/or normal hexane. A feedstock of the following composition is typical:

	<u>Components</u>	<u>Weight-%</u>
	C ₄ minus	4.1
	i-C ₅	24.5
20	n-C ₅	27.8
	i-C ₆	27.4
	n-C ₆	14.7
	C ₇ plus	1.5

In the foregoing description of the preferred feedstocks suitably treated in accordance with the present process, the expression "the various isomeric forms of pentane and hexane" is intended to denote all the branched chain and cyclic forms of the compounds, as well as the straight chain forms. Also, the prefix notations "iso" and "i" are intended to be generic designations of all branched chain and cyclic forms of the indicated compound.

The conditions at which the normal paraffin hydrocarbon isomerization process occurs can vary widely. The isomerization reaction can be conducted over a wide range of temperatures, but, in general, in the range from 90 to 425°C. Preferably, the isomerization temperature is between about 240-300°C and more

preferably between 250-290°C. Space velocities from about 0.25 to about 5 liquid volumes per hour of isomerizable normal paraffin hydrocarbons per packed volume of activated zeolite beta catalyst composition are preferred with reaction zone pressures preferably within the range from 690 kPa (100 psi) to 6900 kPa (1000 psi). It is particularly desirable to carry out the isomerization reaction in the presence of hydrogen preferably in the range from about 0.5 to about 5 moles of hydrogen per mole of isomerizable normal paraffin hydrocarbon. It is not necessary to employ pure hydrogen since hydrogen containing gases are suitable. Product separation facilities of the isomerization process, such as catalytic conversion of naphthas, are suitable sources of hydrogen-rich gases. These hydrogen-rich gases typically contain light hydrocarbons, e.g., C₁-C₃, and may also contain other compounds.

The normal paraffin hydrocarbon conversion process may be carried out in a batch, semi-continuous, or continuous fashion. The process can be conducted in a single reaction zone or a number of reaction zones arranged in series or in parallel, or it may be conducted intermittently or continuously in an elongated tubular zone or a number of such zones. When multiple reaction zones are employed, it may be advantageous to employ one or more of such zeolite beta catalyst compositions in series to provide for a desired product mixture. Owing to the nature of the normal paraffin hydrocarbon isomerization process, it may be desirable to carry out the certain processes by use of the zeolite beta catalyst compositions in a dynamic (e.g., fluidized or moving) bed system or any system of a variety of transport beds rather than in a fixed bed system. Such systems would readily provide for any regeneration (if required) of the zeolite beta catalyst compositions after a given period of time. If regeneration is required, the zeolite beta catalyst compositions can be continuously introduced as a moving bed to a regeneration zone where they can be regenerated, such as for example by removing carbonaceous materials by oxidation in an oxygen-containing atmosphere.

EXAMPLE 1

5.8 g (anhydrous weight) of sodium aluminate was added to 55.6 g of 40% tetraethylammonium hydroxide (TEAOH) in a glass beaker and stirred at room temperature for a period of five minutes. The resulting mixture was heated with stirring to reflux and held for two minutes in order to dissolve the sodium aluminate. The resulting solution was pale yellow and the sodium aluminate was incompletely dissolved. The glass beaker was transferred to a cool stirring hot plate and cooled

with stirring to room temperature. As the solution cooled, additional fine solids appeared in the solution which adhered to the bottom and sides of the glass beaker. The white solid was scraped from the sides of the glass beaker with a teflon spatula and stirred. Once the sodium aluminate/TEAOH solution was cooled, 145.4 g of Ludox LS silica was added gradually. The resulting slurry became very thick and additional hand agitation with the teflon spatula was needed to maintain the mixing of the thickening gel. The gel was mixed on the magnetic stirrer for an additional ten minutes after all the Ludox LS silica had been added. The gel was divided in half and placed in separate teflon liners of about 93 g and 105 g respectively. Each teflon liner was placed in a stainless steel reactor and digested in an oven at a temperature of 150°C. After six days, the two reactors were removed from the oven and cooled overnight. The contents were combined and slurried with an additional 200 milliliters of deionized water and filtered. The solid product was washed with deionized water to a pH < 10. The product was dried at room temperature and, when examined by X-ray powder diffraction, gave the characteristic X-ray powder pattern of zeolite beta. The yield of zeolite beta product was approximately 50 g. Analyzed properties of the zeolite beta product were as follows:

	Na ₂ O, wt. %	0.47
	(TEA) ₂ O, wt. %	18.27
20	(NH ₄) ₂ O, wt. %	-
	Al ₂ O ₃ , wt. %	6.38
	SiO ₂ , wt. %	75.27
	(TEA) ₂ O/Al ₂ O ₃	1.18
	(NH ₄) ₂ O/Al ₂ O ₃	-
25	SiO ₂ /Al ₂ O ₃	20.01

The zeolite beta product was then calcined in flowing air at a temperature of 600°C for a period of 2 hours to decompose the tetra-ethylammonium cation. After cooling, the calcined zeolite beta product was exchanged with NH₄NO₃ solution (5 g NH₄NO₃ per g of calcined zeolite beta product) at reflux (3 times), washed in distilled

water and dried at room temperature. Analyzed properties of the calcined, ammonium-exchanged zeolite beta product were as follows:

	Na ₂ O, wt. %	<0.03
	(TEA) ₂ O, wt. %	-
5	(NH ₄) ₂ O, wt. %	2.69
	Al ₂ O ₃ , wt. %	6.56
	SiO ₂ , wt. %	89.46
	(TEA) ₂ O/Al ₂ O ₃	-
	(NH ₄) ₂ O/Al ₂ O ₃	0.81
10	SiO ₂ /Al ₂ O ₃	23.15

EXAMPLES 2-11

The calcined, ammonium-exchanged zeolite beta product prepared in Example 1 was tested for n-butane cracking activity utilizing a cylindrical quartz tube reactor (254 mm in length and 10.3 mm internal diameter). Normal-butane cracking activity is useful screening test for catalytic activity and is indicative of isomerization activity. Separate samples of the calcined, ammonium-exchanged zeolite beta product were tested for n-butane cracking activity. The reactor was loaded with 0.42 to 0.84 mm sized particles (20-40 mesh) of the calcined, ammonium-exchanged zeolite beta product in an amount of from 0.5 to 5 g. The calcined ammonium-exchanged zeolite beta product was then activated in the reactor for a period of 1 hour in a stream of either flowing helium or flowing air at the activation temperature indicated in Table A. below. The reaction feedstock was a helium-n-butane mixture containing 2 mol. % n-butane and, after activation of the zeolite beta product, was passed through the reactor at a rate of 50 cubic centimeters per minute with the reactor temperature maintained at 500°C. Analysis of the feedstock and the reactor effluent was carried out using conventional gas chromatography techniques. The reactor effluent was analyzed after 10 minutes of on-stream operation. From the analytical data, a pseudo-first-order rate constant (k_A) was calculated.

The results are given in Table A. The lower the value of k_A, the lower the catalytic activity.

Table A

	<u>Example No.</u>	<u>Activation Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
5	2	500 Air	91.3	0.4	126
	3	500 Helium	88.4	1.1	128
10	4	550 Air	89.1	0.2	132
	5	550 Helium	-	-	-
15	6	600 Air	93.1	0.1	184
	7	600 Helium	93.3	0.1	170
	8	650 Air	98.6	0.0	245
20	9	650 Helium	99.7	0.0	305
	10	700 Air	82.2	0.0	60
25	11	700 Helium	-	-	-

EXAMPLES 12-17

In order to demonstrate improved catalytic results from high temperature activation of zeolite beta in accordance with the invention, a series of n-butane cracking tests were conducted with LZ-202 for comparison purposes. LZ-202, an omega type zeolite synthesized in an organic free system, is a known active catalyst for hydrocarbon conversion reactions. Separate samples of ammonium-exchanged LZ-202 product were tested for n-butane cracking activity in accordance with the procedure described in Examples 2-11 above. The results are given in Table B below and show no unusual effect in regard to activity. Typically, a temperature of 550°C in air is observed with most catalytic materials to be the optimum activation temperature for catalysis.

Table B

	<u>Example No.</u>	<u>Activation Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
5	12	500 Air	76.8	4.1	71
	13	500 Helium	82.1	3.5	57
10	14	550 Air	85.5	3.1	100
	15	550 Helium	74.1	4.0	60
15	16	600 Air	62.5	4.6	56
	17	600 Helium	56.0	5.0	37

EXAMPLE 18

51.74 g (anhydrous weight) of sodium aluminate were added to 361.4 g of
 20 40% tetraethylammonium hydroxide (TEAOH) and mixed on a magnetic stirrer for a
 period of five minutes at room temperature before heating to reflux. The sodium
 aluminate did not completely dissolve. The resulting slurry was transferred to a plastic
 beaker and stirred with a Heidolph mixer fitted with a jiffy pain mix stirrer until it
 cooled. As the slurry cooled, additional precipitate formed. When cool, 945.1 g of
 25 Ludox LS silica were gradually added with stirring to the sodium aluminate/TEAOH
 slurry. A very thick gel formed and additional hand agitation was needed to keep the
 slurry mixing. After all the Ludox LS silica had been added, the gel was mixed for a
 period of five minutes and it thinned slightly. 1295.5 g of the gel were transferred to a
 two liter reactor and digested for a period of seven days at a temperature of 155°C.
 30 The reactor was then cooled overnight. Initial filtration was slow, but as the product
 was washed with deionized water, filtration became easier. After washing until the pH
 of the filtrate was less than 10, the solid product was dried at room temperature and
 fully characterized. This preparation had a yield of 350 g. It had the characteristic X-
 ray powder pattern of zeolite beta. Analyzed properties of the zeolite beta product
 35 were as follows:

	Na ₂ O, wt. %	0.85
	(TEA) ₂ O, wt. %	15.63
	(NH ₄) ₂ O, wt. %	-
	Al ₂ O ₃ , wt. %	6.12
5	SiO ₂ , wt. %	77.40
	(TEA) ₂ O/Al ₂ O ₃	0.94
	(NH ₄) ₂ O/Al ₂ O ₃	-
	SiO ₂ /Al ₂ O ₃	21.44

The zeolite beta product was then calcined in flowing air at a temperature of 600°C for a period of 2 hours to decompose the tetra-ethylammonium cation. After cooling, the calcined zeolite beta product was exchanged with NH₄NO₃ solution (5 g NH₄NO₃ per g of calcined zeolite beta product) at reflux (3 times), washed in distilled water and dried at room temperature. Analyzed properties of the calcined, ammonium-exchanged zeolite beta product were as follows.

15	Na ₂ O, wt. %	<0.03
	(TEA) ₂ O, wt. %	-
	(NH ₄) ₂ O, wt. %	2.78
	Al ₂ O ₃ , wt. %	6.03
	SiO ₂ , wt. %	90.26
20	(TEA) ₂ O/Al ₂ O ₃	-
	(NH ₄) ₂ O/Al ₂ O ₃	0.90
	SiO ₂ /Al ₂ O ₃	25.39

EXAMPLES 19-28

Separate samples of the calcined, ammonium-exchanged zeolite beta product prepared in Example 18 were tested for n-butane cracking activity in accordance with the procedure described in Examples 2-11 above. The results are given in Table C below.

Table C

	<u>Example No.</u>	<u>Activation Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
5	19	500 Air	87.6	1.7	139
	20	500 Helium	85.5	1.0	120
10	21	550 Air	85.2	0.5	123
	22	550 Helium	-	-	-
15	23	600 Air	95.0	0.0	182
	24	600 Helium	95.4	0.1	173
	25	650 Air	98.1	0.0	210
20	26	650 Helium	97.6	0.0	230
	27	700 Air	65.1	0.4	71
25	28	700 Helium	-	-	-

In order to demonstrate the unique nature of this invention, the following Examples 29-36 were conducted wherein the required activation step or one or more of the preferred treatment steps were omitted, i.e., calcination, and/or ion-exchange.

EXAMPLES 29-32

30 A zeolite beta product was prepared in accordance with the procedure described in Example 18 above except without the final activating step and without the ammonium exchange step. The zeolite beta product was tested for n-butane cracking activity in accordance with the procedure described in Examples 2-11 above. The results are given in Table D below. The results demonstrate inferior
 35 activity of this zeolite beta product in comparison with zeolite beta product prepared according to this invention and further demonstrate the importance of the required catalyst preparation step.

Table D

5	<u>Example No.</u>	<u>Calcination Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
	29	550 Air	23.5	6.9	22
	30	600 Air	44.8	2.3	63
10	31	650 Air	33.9	3.6	43
	32	700 Air	46.6	1.2	43

EXAMPLE 33

15 A zeolite beta product was prepared in accordance with the procedure described in Example 18 above except without the initial calcination step to oxidize the catalyst templating agent. The zeolite beta product was ammonium-exchanged and activated at a temperature of 550°C in air and thereafter tested for n-butane cracking activity in accordance with the procedure described in Examples 2-11 above.

20 The results are given in Table E below. The results demonstrate inferior activity of this zeolite beta product in comparison with zeolite beta product prepared according to this invention and further demonstrate the importance of the required catalyst preparation steps.

Table E

25	<u>Example No.</u>	<u>Activation Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
30	33	550 Air	50.2	3.7	67

EXAMPLE 34

A zeolite beta product was prepared in accordance with the procedure described in Example 18 above except without the ammonium exchange step. Instead, the zeolite beta product was hydronium ion-exchanged after the initial calcination

35 step. The zeolite beta product was tested for n-butane cracking activity in accordance with the procedure described in Examples 2-11 above. The results are given in Table F below. The results demonstrate that hydronium-exchanged zeolite beta results in inferior activity in comparison with ammonium-exchanged zeolite beta.

Table F

5	<u>Example No.</u>	<u>Activation Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
	34	550 Air	3.5	2.1	4

EXAMPLES 35-36

10 A zeolite beta product was prepared in accordance with the procedure described in Example 18 above except the zeolite beta product was hydrothermally treated with steam at a temperature of 600°C following the ammonium exchange step. The product resulting from the steaming was fully crystalline. The zeolite beta product was then activated at a temperature of 650°C and thereafter tested for n-butane cracking activity in accordance with the procedure described in Examples 2-11 15 above. The results are given in Table G below. The results demonstrate that hydrothermal steam calcination or activation of zeolite beta product results in inferior activity in comparison with thermal calcination or activation by heating in air or an inert atmosphere.

Table G

20	<u>Example No.</u>	<u>Activation Temperature (°C)</u>	<u>% Consumption of n-Butane</u>	<u>% i-Butane in Product</u>	<u>kA</u>
25	35	650 Helium	2.8	21.1	2
	36	650 Helium	5.1	18.8	3

EXAMPLE 37

30 100 g of calcined, ammonium-exchanged zeolite beta product prepared as in Example 18 were slurried in a beaker in one liter of distilled water. A second solution containing 0.60 g of Pt(NH₃)₄Cl₂ dissolved in 500 milliliters of distilled water was then added to the zeolite slurry and the zeolite beta was platinum-exchanged. The resulting slurry was then filtered and washed with distilled water, dried, extruded with peptized alumina binder and dried again for a period of sixteen hours. The 35 extrudates contained 0.32 wt.% platinum. The extrudates were split into two batches, one batch was calcined in air at a maximum temperature of 650°C (hereinafter

Catalyst A) and the second batch was calcined in air at a maximum temperature of 540°C (hereinafter Catalyst B).

EXAMPLE 38

Separate samples of Catalyst A and Catalyst B prepared in Example 37
 5 above were evaluated for C₅/C₆ isomerization activity using a fixed bed microreactor unit comprising a stainless steel tube (16 mm internal diameter). About 8.0 to 12.0 g of selected Catalyst A or Catalyst B sized to 0.25 to 0.42 mm were loaded in the microreactor and reduced under a flow of hydrogen gas at a temperature of greater than 200°C for a period of sixteen hours. A feed consisting of 60 wt.% n-C₅, 35 wt.%
 10 n-C₆ and 5 wt.% cyclohexane was then introduced into the microreactor at a reaction pressure of 1827 kPa (250 psig), a weight hourly space velocity (WHSV) of 1.6 hr.⁻¹, a hydrogen/hydrocarbon feed molar ratio of 2 and a reaction temperature specified in Table H below. Products were collected at selected run times and the products were analyzed by gas chromatography. The products were evaluated in several respects by
 15 determining:

$$\begin{array}{l}
 \text{i-C}_5 \text{ Conversion} = \frac{\text{i-C}_5}{\text{i-C}_5 + \text{n-C}_5} \\
 \\
 \text{2,2-DMB (Dimethylbutane) Conversion} = \frac{\text{2,2-DMB}}{\text{Total C}_6 \text{ Paraffins}}
 \end{array}$$

as a means to determine the relative extent of conversion of pentane and hexane to isomeric products. The results are set forth in Table H below.

Table H

5	<u>Catalyst</u>	<u>Reaction Temperature (°C)</u>	<u>i-C₅ Conversion</u>	<u>2,2-DMB Conversion</u>	<u>C₅⁺ Yield</u>
	A	251.7	62.9	18.1	98.5
	A	260.0	68.1	19.0	97.3
	A	265.6	69.2	19.2	95.7
10	A	273.9	69.1	19.0	92.4
	B	251.7	55.7	13.5	98.9
	B	260.0	63.1	15.1	97.8
	P	265.6	66.5	16.1	96.5
	B	273.9	68.9	18.0	93.7

15 The results set forth in Table H above are graphically illustrated in Figure 1 and Figure 2.

20 Figure 1 graphically illustrates the relationship between C₅ isomerization conversion and C₅⁺ yield as demonstrated by the isomerization process described in Example 39, in particular, the relationship between wt.% i-C₅ of total C₅ paraffins and the wt.% C₅⁺ yield, utilizing a zeolite beta catalyst activated at a temperature of 650°C, a zeolite beta catalyst activated at a temperature of 540°C and a standard reference catalyst as identified in Example 39.

25 Figure 2 graphically illustrates the relationship between C₆ isomerization conversion and C₅⁺ yield as demonstrated by the isomerization process described in Example 39, in particular, the relationship between wt.% 2,2-DMB (dimethylbutane) of total C₆ paraffins and the wt.% C₅⁺ yield, utilizing a zeolite beta catalyst activated at a temperature of 650°C, a zeolite beta catalyst activated at a temperature of 540°C and a standard reference catalyst as identified below.

30 It can be seen from Figures 1 and 2 that both the catalytic activity, i.e., conversion, and selectivity, i.e., yield, were substantially enhanced when the catalyst was activated at 650°C as compared to 540°C. The delta i-C₅ conversion, delta 2,2-DMB conversion and delta RON (Research Octane Number) based on a standard

reference catalyst were calculated at 96% C₅⁺ yield using a 60:40 wt.% n-C₅ : n-C₆ feed composition as follows:

$$\text{delta i-C}_5 \text{ Conversion} = \text{i-C}_5 \text{ conversion} - 63.00$$

$$\text{delta 2,2-DMB Conversion} = \text{2,2-DMB conversion} - 17.00$$

$$\begin{aligned} \text{5} \quad \text{delta RON} &= 0.60 \times 0.33 (\text{i-C}_5 \text{ conversion} - 63.00) + \\ &0.40 \times 0.65 (\text{2,2-DMB conversion} - 17.00) \end{aligned}$$

The standard reference catalyst was a platinum on H-mordenite catalyst having an i-C₅ conversion of 63% and a 2,2-DMB conversion of 17%. In the formula; 0.60 and 0.40 denote the n-pentane and n-hexane composition of the feed in weight fraction, 10 0.33 denotes the RON octane difference between isopentane (RON=94) and normal pentane (RON=71) divided by 100, and 0.65 denotes the octane difference between 22DMB (RON=94) and n-hexane (RON=29) divided by 100. The results are set forth in Table I below as follows:

15 TABLE I

<u>Catalyst</u>	<u>delta i-C₅ Conversion</u>	<u>delta 2-2-DMB Conversion</u>	<u>Delta RON</u>
A	6.25	2.25	1.82
B	4.40	-0.39	0.80
20 HS-10	0.0	0.0	0.0

The results from Table I show superior catalytic performance of zeolite beta activated at a temperature of 650°C in a C₅/C₆ isomerization process in comparison with the catalytic performance of the same catalyst activated at a 25 temperature of 540°C, the typical activation temperature.

EXAMPLE 39

Approximately 1 g samples on a dry weight basis of the ammonium ion-exchanged zeolite beta, as prepared in Example 1, were activated in a shallow bed under flowing dry air for 2 hours, removed from the oven and placed in a desiccator to 30 cool, then placed in a 50 ml solution of 3.5 M NaCl solution. Potentiometric titrations were then developed with 0.1 N NaOH solution. The result of the titrations shows the

amount and type of acidity developed by the zeolite under the various activation conditions.

Four samples were activated at 450, 540, 650 and 700°C and the potentiometric titrations for each sample were developed as described above. The results are plotted in Figure 3. After 450°C calcination, two types of acidity were determined, strong acidity from a hydrated proton, H_3O^+ and a weaker acid species of hydroxoaluminum cations, $\text{Al}(\text{OH})_2^+$. As the activation temperature was increased, the amount of strong acid decreased as the amount of the weaker acid species increased. Without being bound by any definitive theory, it can be observed that the decrease in strong acidity is accompanied by an increase in weak acidity which corresponds well with the observed isomerization activity shown in Example 38 and Figures 1 and 2, and also the n-butane cracking activity shown in Examples 2-11. As the strong acidity (H_3O^+), decreases and the weak acidity increases ($\text{Al}(\text{OH})_2^+$), the isomerization activity increases. Enhanced isomerization activity occurs when the strong acidity is no longer observed in the titration and when the weak acidity is also at a maximum. As the weak acidity decreases with calcination above 650°C, the isomerization activity will also be expected to decrease based on the k_A values for n-butane cracking, see Examples 2-11.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A process for isomerizing normal paraffin hydrocarbons to form non-normal paraffin hydrocarbons comprising the steps of:

(a) heating an initial zeolite beta catalyst in air or an inert atmosphere at an initial temperature of less than 540°C effective to form an initial concentration of weak acid species and strong acid species and continuing said heating at an activation temperature of from 600° to 700°C effective to substantially reduce or to substantially eliminate the concentration of strong acid species without substantially reducing the concentration of weak acid species to form an activated zeolite beta catalyst;

(b) passing a feedstock comprising said normal paraffin hydrocarbons and hydrogen to an isomerization zone containing said activated catalyst at an isomerization temperature at least 300°C lower than said activation temperature and effective to convert at least a portion of said normal paraffin hydrocarbons into said non-normal paraffin hydrocarbons; and

(c) withdrawing a product stream comprising said non-normal paraffin hydrocarbons.

2. The process of Claim 1 wherein the activation temperature is effective to reduce the concentration of strong acid species by at least 50% as compared to the concentration of strong acid species remaining after activating at 540C.

3. The process of Claim 1 or Claim 2 wherein the activation temperature is effective to increase the concentration of weak acid species as compared to the concentration of weak acid species remaining after activating at 540°C.

DATED this 13th day of September, 1993.

UQP

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**"ACTIVATED ZEOLITE BETA CATALYST
AND ISOMERIZATION PROCESS THEREFOR"**

5

ABSTRACT

10 Normal paraffin hydrocarbons are isomerized to produce products containing non-normal hydrocarbons using a novel zeolite beta catalyst that has been activated in order to enhance its catalytic properties by treating at an activation temperature effective to substantially reduce the concentration of strong acid species, i.e., hydronium cations, without substantially reducing the concentration of weak acid species, i.e., hydroxoaluminum cations, both of said strong acid species and weak acid species being initially present on the catalyst prior to activation. The isomerization step is preferably thereafter conducted at a temperature at least 300°C lower than the activation temperature.

*C₅ Isomerization vs. C₅+ Yield
Zeolite Beta*

(Calcined, Ammonium And Platinum Exchanged, Activated)

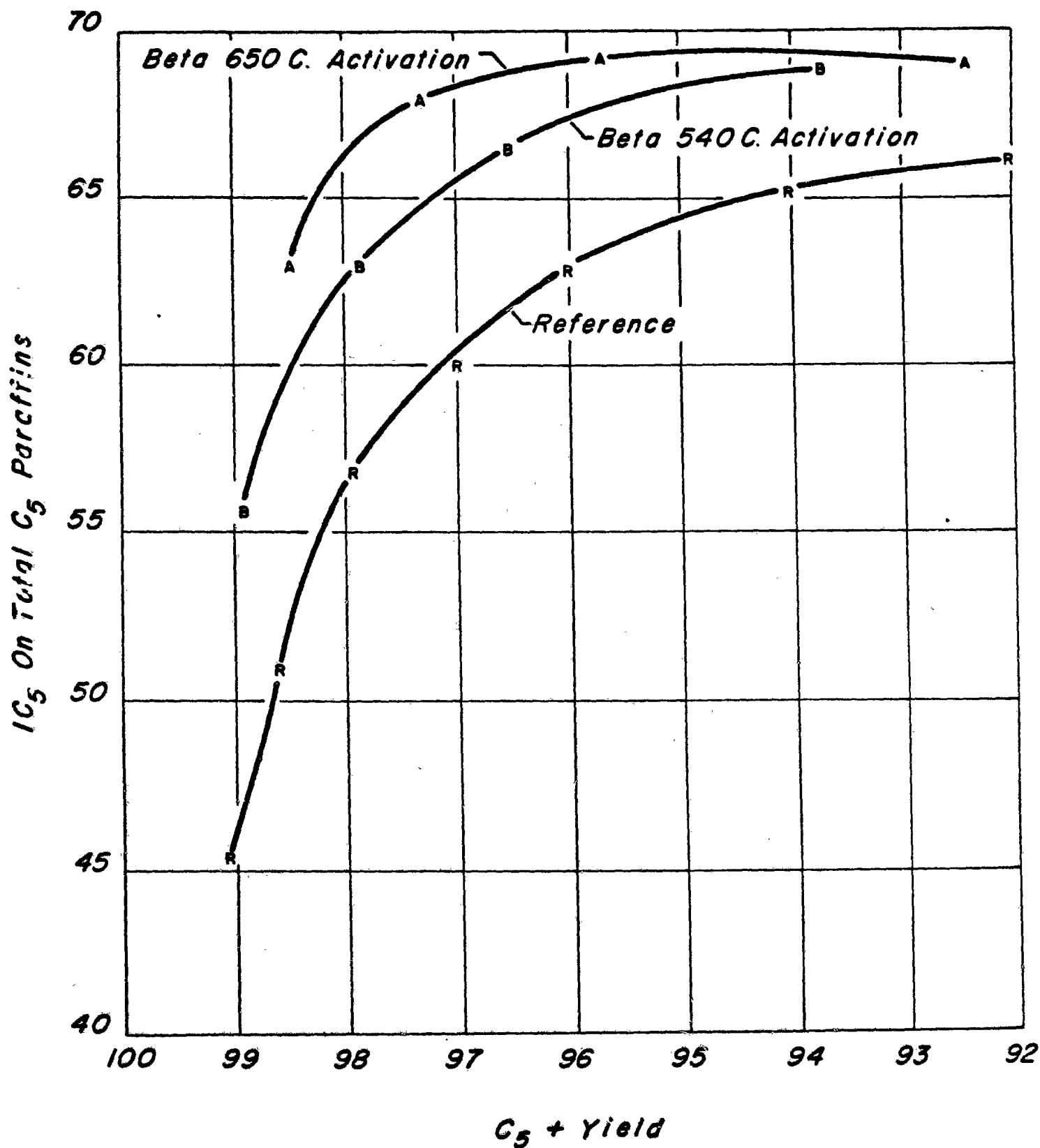


Figure 2

C_6 Isomerization vs. $C_5 +$ Yield Zeolite Beta

(Calcined, Ammonium And Platinum Exchanged, Activated)

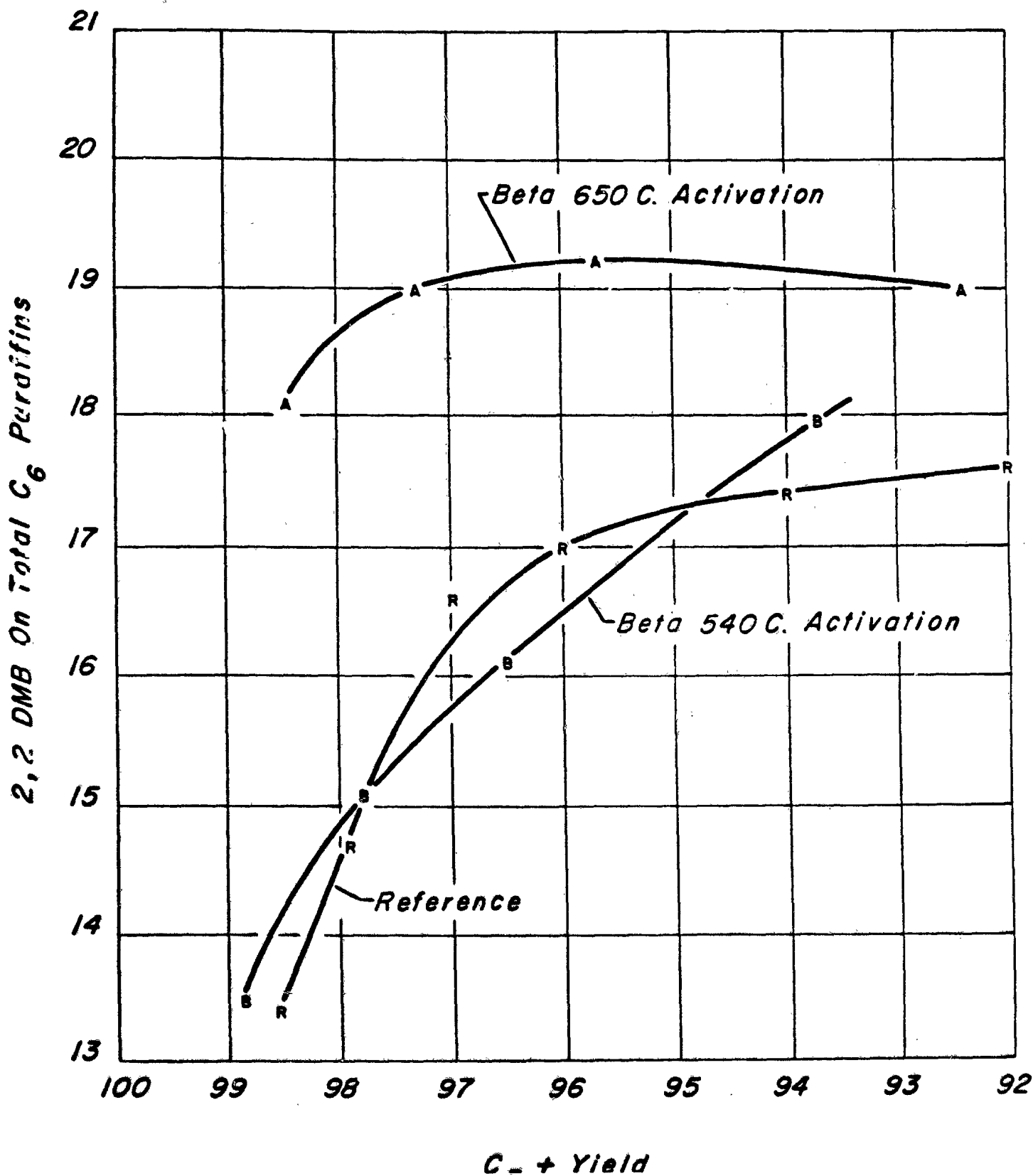


Figure 3

Acidity Of Zeolite Beta

