

**IONIC LIQUID ALKYLATION OF ISOBUTANE WITH BIO-ETHYLENE TO
PRODUCE ALKYLATE**

CROSS-REFERENCE OF RELATED APPLICATIONS

[001] This application claims the priority benefit of U.S. Provisional Patent Application No. 63/289,703, filed December 15, 2021, the disclosure of which is incorporated herein by reference.

FIELD

[002] This present disclosure relates a process for isoparaffin-olefin alkylation. More specifically, the present disclosure relates to a process for producing a high octane bio-based alkylate by reacting isobutane with bio-ethylene in the presence of an acidic ionic liquid catalyst.

BACKGROUND

[003] Because of its clean-fuel properties (e.g., high octane rating, low-vapor pressure, and low sulfur content), alkylate is considered one of the most desired components in the gasoline pool. As demand for cleaner-burning fuel has increased, refiners are relying more than ever on alkylate to meet stringent gasoline specifications. With increasing pressure to reduce motor vehicle exhaust emissions, alkylate is well-positioned to be in steady demand for decades to come.

[004] Most alkylate is produced in refineries by a process known as isoparaffin alkylation. Commercially, isoparaffin alkylation is an acid catalyzed reaction that combines C3-C5 light olefins from a fluid catalytic cracking (FCC) unit with isobutane to produce a relatively high octane branched-chain paraffinic hydrocarbon fuel, including iso-heptane and iso-octane. Predominant alkylation technologies utilized by refiners require a liquid acid catalyst such as sulfuric acid (H₂SO₄) or hydrofluoric acid (HF).

[005] Ethylene is another major component produced in the FCC unit. However, the direct alkylation of ethylene has not been possible with conventional liquid acid alkylation catalysts (e.g., H_2SO_4 , HF) and processes due to the relatively slow kinetics of the reaction. Efforts to produce alkylate from ethylene have relied on dimerizing ethylene to butylene in a dimerization process unit, followed by alkylation with isobutane in the alkylation process unit. This method requires significant extra capital investment for the dimerization unit. In addition, alkylate yield per barrel of ethylene is very low.

[006] In order to encourage the production and consumption of biofuels in the United States, regulatory agencies have taken steps to mandate and incentivize increased production of fuels from renewable sources. For example, the Renewable Fuel Standard (RFS) program requires renewable fuel to be blended into transportation fuel in increasing amounts each year, escalating to 36 billion gallons by 2022. The chief renewable-sourced gasoline blendstock used in the United States to meet the gasoline blending requirement is ethanol, produced largely from availability from agricultural sources. A technical disadvantage of ethanol as a fuel blendstock is that ethanol has lower energy density than typical gasoline components. Another technical disadvantage of ethanol is its very high blending Reid Vapor Pressure (RVP). Therefore, alternative bio-based gasoline blending components are desired.

[007] Therefore, there is a need for an improved process for alkylation of light olefins, particularly light olefins from renewable resources.

SUMMARY

[008] In one aspect, there is provided a process for making an alkylate, the process comprising: (a) dehydrating a

bioethanol feed to form an impure bio-ethylene mixture; (b) recovering a bio-ethylene stream from the impure bio-ethylene mixture; and (c) passing an isobutane feed stream and the bio-ethylene stream to an alkylation reactor, wherein the alkylation reactor contains an ionic liquid, the ionic liquid comprising an organic cation and a halometallate anion, for reacting the isobutane and bio-ethylene to generate an alkylate having a research octane number (RON) of 93 or more; wherein the alkylation reactor is operated at reaction conditions including a temperature of from 30°C to 100°C, a pressure of from 300 psig to 700 psig (2068 kPa to 4826 kPa), an overall paraffin to olefin molar ratio from 2 to 20, and a residence time of from 5 minutes to 1 hour.

[009] In another aspect, there is provided an alkylate having a research octane number (RON) of 93 or more, comprising: (i) at least 70 wt. % C6 paraffins, wherein the C6 paraffins comprise isomers of dimethylbutane (DMB) and methylpentane (MP) and a molar ratio of DMB to MP is at least 7:1; (ii) 30 wt. % or less C8 paraffins; and (iii) less than 20 wt. % C9+ paraffins; wherein the alkylate has a bio-based carbon content in a range of from 1% to 100%, according to ASTM D6866-21.

BRIEF DESCRIPTION OF THE DRAWINGS

[010] FIG. 1 is an illustration of one embodiment of an alkylation process of the present disclosure.

[011] FIG. 2 shows a plot of alkylate boiling point (ASTM D86) as a function of percent volume boiled for isobutane-ethylene alkylation at various temperatures.

DETAILED DESCRIPTION

Definitions

[012] The prefix "bio-" is used herein to designate a material that has been derived from a renewable resource. As

used herein, a "renewable resource" is one that is produced by a natural process at a rate comparable to its rate of consumption (e.g., within a 100-year time frame). The resource can be replenished naturally or via agricultural techniques. Natural resources of fossil origin such as crude oil, coal, shale, and natural gas, which take longer than 100 years to form, are not considered renewable resources.

[013] The term "alkylate" means the reaction products generated in alkylation reactions between an olefin and an isoparaffin in the presence of a catalyst. Alkylates typically are highly branched paraffinic hydrocarbons. Refiners can use alkylate as a gasoline blend stock to boost octane, reduce Reid vapor pressure (RVP), and reduce olefin content in a final gasoline blend.

[014] The term "C_n hydrocarbons" or "C_n", wherein "n" is a positive integer, means hydrocarbons having "n" number of carbon atoms per molecule. The term "C_n+" is meant to describe a mixture of hydrocarbons having "n" or more carbon atoms. The term "C_n-" is meant to describe to a mixture of hydrocarbons having "n" or less carbon atoms.

[015] The term "octane number" refers to the percentage of iso-octane in a mixture of iso-octane and n-heptane that would have the same knock resistance as the presently tested fuel, according to ASTM D2699 and D2700. Octane numbers typically range from 0 to 100, with higher values indicating better fuel performance. Octane numbers are unitless.

[016] The term "Research Octane Number" (RON) refers to the octane number obtained by testing at lower engine speed and temperature, typically about 600 rpm, according to ASTM D2699.

[017] The term "Motor Octane Number" (MON) refers to the octane number obtained by testing at higher engine speed and temperature, typically about 900 rpm according to ASTM

D2700. Given that engine inefficiency inherently increases as temperature increases, RON is typically higher than MON.

[018] "Anti-knock index" is defined by the arithmetic average of the two octane numbers: $(RON+MON)/2$.

[019] The term "Reid vapor pressure" (RVP) refers to the absolute vapor pressure exerted by a liquid at 100°F (37.8°C), as determined by ASTM D323.

[020] The density of a fuel formulation or fuel component can be measured using ASTM D4052.

[021] The terms "wt. %", "vol. %", or "mol. %" refers to a weight, volume, or molar percentage of a component, respectively, based on the total weight, the total volume of material, or total moles, that includes the component. In a non-limiting example, 10 grams of component in 100 grams of the material is 10 wt. % of component.

Isobutane Feed

[022] The isobutane feed stream to alkylation unit generally comprises at least 50 wt. % isobutane (e.g., 50 wt. % to 99 wt. % isobutane, or 50 wt. % to 95 wt. % isobutane, or 55 wt. % to 90 wt. % isobutane, or at least 80 wt. % isobutane, or 80 wt. % to 98 wt. % isobutane, or 90 wt. % to 97 wt. % isobutane), with at least 90 wt. % (e.g., at least 99 wt. %) of the remainder comprising n-butane. The isobutane feed may be substantially free of one or more of (i) butenes, including isobutene, (ii) C5+ hydrocarbon, and (iii) C3-hydrocarbon. In this context, the term "substantially free" means the isobutane feed comprises less than or equal to 1.0 wt. % of the designated compounds (e.g., less than or equal to 0.1 wt. %, or less than or equal to 0.01 wt. %, or less than or equal to 0.001 wt. %).

Bio-Ethylene Feed

[023] The bio-ethylene feed used in the present alkylation process may be obtained by dehydration from bioethanol, which in turn can be made from biomass-derived

sugars and starch and from syngas through a biological fermentation process.

[024] Representative sources of biomass include corn, wheat, sugar beet, sugarcane, sorghum, potatoes, corn stover, wheat straw, bagasse, wood chips, switchgrass, pulp, paper waste, and algae.

[025] In some aspects, the bioethanol feed may be obtained from biomass-generated syngas. In other aspects, the bioethanol feed is obtained from a combination of biomass-generated syngas and syngas that has been derived from natural gas, coal, or a combination of natural gas and coal.

[026] Bioethanol or bioethanol-containing feeds may be fed to a dehydration reactor optionally with an inert gas such as nitrogen, pre-heated to a selected reaction temperature, and passed over a dehydration catalyst at a temperature and pressure sufficient to carry out the dehydration reaction that forms bio-ethylene.

[027] In some aspects, at least 60 wt. % (e.g., at least 70 wt. %, or at least 80 wt. %, or at least 90 wt. %, or at least 95 wt. %, or at least 99 wt. %) of the ethanol in the bioethanol feed is derived from a non-petroleum feedstock. In such aspects, the ethanol is produced in an ethanol bio-refinery via the fermentation of sugars by yeast.

[028] The bioethanol feed may be an azeotropic ethanol-water mixture obtained from a bioethanol production plant. The azeotropic ethanol-water mixture may be obtained from a bioethanol production plant prior to dehydration of the azeotropic ethanol-water mixture. The molar concentration of ethanol in the ethanol-water mixture may be about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, or 95% ethanol.

[029] The bioethanol feed may comprise ethanol and at least one constituent selected from water, methanol, one or more fusel alcohols, one or more diluents, and combinations

thereof. In some aspects, the bioethanol feed comprises water at a molar concentration of less than 30%, less than 25%, less than 20%, less than 15%, less than 12%, less than 10%, or less than 5%.

[030] In one aspect, the bioethanol feed consists of ethanol and water. In another aspect, the bioethanol reactor feed consists of ethanol, water, and methanol. In still another aspect, the reactor feed consists essentially of ethanol, water, methanol, and one or more fusel alcohols.

[031] Fusel alcohols are by-products of fermentation processes utilized in the production of bioethanol. The fusel alcohol may be selected from 1-propanol, isobutanol, 2-methyl-1-butanol, isopentanol, and mixtures thereof. The bioethanol feed may comprise less than 2 wt. %, or less than 1 wt. %, or less than 0.5 wt. %, or less than 0.1 wt. %, or less than 0.05 wt. % fusel alcohol. In some aspects, the bioethanol feed is free of a fusel alcohol.

[032] The diluent may be used to reduce the concentration of the active ingredients in the feed and is generally non-reactive to the active ingredients in the feed or catalyst composition. The diluent may be selected from carbon dioxide, nitrogen, methane, ethane, propane, and mixtures thereof. The amount of diluent in the feed may be in a range of from 1 to 99 mol. % (e.g., 5 to 50 mol. %, or 5 to 25 mol. %), based on the total number of moles of the feed and diluent.

[033] The dehydration of bioethanol to bio-ethylene may be accomplished catalytically.

[034] The dehydrating step may use homogeneous and/or heterogeneous catalysts. The catalyst may be a solid acid selected from the group consisting of an inorganic oxide (e.g., γ - Al_2O_3 , MgO/SiO_2), a molecular sieve (e.g., ZSM-5), and a heteropolyacid (e.g., tungstophosphoric acid, molybdophosphoric acid). In some aspects, dehydration of

ethanol to ethylene may be accomplished by using biocatalysts such as enzymes.

[035] The dehydration may be conducted at a temperature of from 150°C to 500°C (e.g., 200°C to 450°C, or 250°C and 400°C).

[036] The dehydration may be conducted at a pressure of from 100 to 2000 kPa (e.g., 200 to 1000 kPa, or 200 to 700 kPa).

[037] The dehydration may be conducted at a weight hourly space velocity (WHSV) in a range of from 0.5 to 10 h⁻¹ (e.g., 1 to 9 h⁻¹, or 2 to 8 h⁻¹). The WHSV represents the weight flow rate of the alcohol at the inlet of the reactor divided by the mass of the catalyst in the reactor.

[038] The dehydration of bioethanol may be carried out in either a batch or continuous mode.

[039] The dehydration may be conducted in any type of reactor. The dehydration reactor can be a fixed bed reactor (radial, isothermal, adiabatic, etc.), a moving bed reactor, multi-tubular or a fluidized bed reactor.

[040] The raw bio-ethylene stream from the dehydration reactor may include bio-ethylene, water, diethyl ether, and small amounts of other materials (e.g., acetaldehyde, hydrogen and light hydrocarbons). Bio-ethylene may be recovered from the impure bio-ethylene mixture by conventional means, such as distillation. After separation, the recovered bio-ethylene stream may include, for example, at least 95% ethylene, at least 99% ethylene, the impurities being hydrogen, methane, ethane, or propane.

[041] The dehydration process can have a high selectivity for ethylene. In some aspects, the selectivity for ethylene in the dehydration process is at least 90% (e.g., at least 95%, or at least 99%).

Ionic Liquid

[042] The ionic liquid comprises an organic cation and an anion. The organic cation is generally a nitrogen-based cation, a phosphorus-based cation, or a combination thereof. Representative organic cations include ammonium, pyrrolidinium, pyridinium, imidazolium, and phosphonium cations.

[043] Examples of ammonium cations include tetraalkylammonium cations, such as tri(C1-C6 alkyl)-(C2-C10 alkyl)ammonium cations. Representative ammonium cations include trimethyl-n-propylammonium, n-butyl-trimethylammonium, n-hexyl-trimethylammonium, triethyl-methylammonium, tetraethylammonium, n-butyl-triethylammonium, and tetra-n-butylammonium.

[044] Examples of pyrrolidinium cations include N-alkylpyrrolidinium cations, such as N-(C2-C6 alkyl)pyrrolidinium cations, and N,N-dialkylpyrrolidinium cations, such as N-(C1-C3 alkyl)-N-(C2-C6 alkyl)pyrrolidinium cations. Representative pyrrolidinium cations include N-propylpyrrolidinium, N-butylpyrrolidinium, N-methyl-N-propylpyrrolidinium and N-butyl-N-methylpyrrolidinium.

[045] Examples of imidazolium cations include 1,3-dialkylimidazolium cations, such as 1-(C2-C10 alkyl)-3-(C1-C3 alkyl)imidazolium cations. Representative imidazolium cations include 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium, 1-n-hexyl-3-methylimidazolium, and 1-n-octyl-3-methylimidazolium.

[046] Examples of pyridinium cations include N-alkylpyridinium cations, such as N-(C2-C6 alkyl)pyridinium cations, and N-alkyl-alkylpyridinium cations, such as N-(C2-C6 alkyl)-(C1-C3 alkyl)pyridinium cations. Representative pyridinium cations include N-ethylpyridinium, N-butylpyridinium, N-propyl-4-methylpyridinium and N-butyl-4-methylpyridinium.

[047] Examples of phosphonium cations include tetraalkylphosphonium cations, such as tri(C1-C10 alkyl)-(C2-C20 alkyl)phosphonium cations. Representative phosphonium cations include triethyl-pentylphosphonium, tetrabutylphosphonium, and trihexyl-tetradecylphosphonium.

[048] The anion of the ionic liquid comprises a halometallate. Halometallate anions may contain a metal selected from Al, Ga, In, Mn, Fe, Co, Ni, Cu, Zn, or combinations thereof, and a halide selected from F, Cl, Br, I, or combinations thereof. In some aspects, the anion of the ionic liquid comprises a haloaluminate. In some aspects, the anion of the ionic liquid comprises a chloroaluminate. For catalytic applications requiring Lewis acidity (such as alkylation), the ratio of moles of halide to moles of metal in the halometallate anion is less than 4. The anion may be formally an anion or it may be an anion associated with a metal halide. For instance, the anion may be AlCl_4^- or Al_2Cl_7^- associated with AlCl_3 . In some aspects, the anion may be GaCl_4^- or Ga_2Cl_7^- or $\text{Ga}_3\text{Cl}_{10}^-$ associated with GaCl_3 .

[049] The ionic liquid catalyst can include a co-catalyst (or catalyst promoter) to enhance the activity of the ionic liquid catalyst by boosting its overall acidity. The co-catalyst may be a Brønsted acid and/or a Brønsted acid precursor. The co-catalyst is present in an amount of 0.05 mol to 1 mol of co-catalyst per mol of ionic liquid, or 0.05 mol to 0.7 mol, or 0.05 mol to 0.5 mol, or 0.1 mol to 0.7 mol, or 0.1 mol to 0.5 mol. Suitable Brønsted acids include HCl, HBr, HI, and combinations thereof. In some aspects, the co-catalyst can be generated in situ from appropriate Brønsted acid precursors. Suitable Brønsted acid precursors include chloroalkanes such as 1-chloropropane, 2-chloropropane, 1-chlorobutane, 2-chlorobutane, 1-chloro-2-methylpropane, 2-chloro-2-methylpropane, and other chloroalkanes, preferably secondary or tertiary chloroalkanes, or combinations thereof.

In some aspects, the Brønsted acid precursor is a chloroalkane having more than one chloride atom per molecule such as dichloromethane, chloroform, carbon tetrachloride, tetrachloroethylene, tetrachloropropene, or combinations thereof.

Alkylation

[050] Typical alkylation reaction conditions include a minimum temperature of 30°C, or 35°C, or 40°C, or 45°C, or 50°C, or 55°C, or 60°C; additionally or alternatively, a maximum temperature of 100°C, or 95°C, or 90°C, or 85°C, or 80°C, or 75°C, or 70°C. Generally, the temperature can be in a range from any minimum temperature disclosed herein to any maximum temperature disclosed herein. It is preferred to have the ionic liquid that maintains its liquid state through the operating temperature range.

[051] The alkylation reaction can be conducted at a pressure of from 100 psig to 1000 psig (689 kPa to 6895 kPa), such as 300 psig to 700 psig (2068 kPa to 4826 kPa), or 350 psig to 500 psig (2413 kPa to 3447 kPa). Preferably, the reactants are maintained in a liquid state at the operating pressure.

[052] The residence time of the reactants in the reaction zone is in a range of from a few seconds to several hours (e.g., 30 seconds to 1 hour, or 2 minutes to 30 minutes, or 2 minutes to 10 minutes, or 5 minutes to 1 hour, or 5 minutes to 30 minutes, 5 minutes to 10 minutes).

[053] The volume of ionic liquid in the reactor may be in a range of from 1 vol. % to 75 vol. % of the total volume of material in the reactor (ionic liquid and hydrocarbons), or 1 vol. % to 70 vol. %, or 1 vol. % to 65 vol. %, or 1 vol. % to 60 vol. %, or 1 vol. % to 55 vol %, or 1 vol % to 50 vol %, or 1 vol. % to 45 vol. %, or 1 vol. % to 40 vol. %, or 1 vol. % to 35 vol. %, or 1 vol. % to 30 vol. %, or 1 vol. % to 25 vol. %, or 1 vol. % to 20 vol. %, or 1 vol.

% to 15 vol %, or 1 vol. % to 10 vol. %, or 1 vol. % to 5 vol. %. In aspects where the volume of ionic liquid in the reactor is less than 50 vol. %, the reaction mixture comprises a dispersed ionic liquid phase and a continuous hydrocarbon phase. In aspects where the volume of ionic liquid in the reactor is greater than 50 vol. %, the reaction mixture comprises a dispersed hydrocarbon phase and a continuous ionic liquid phase.

[054] Due to the low solubility of hydrocarbons in ionic liquids, isoparaffin-olefin alkylation, like most reactions in ionic liquids, is generally biphasic. The catalytic alkylation reaction is generally carried out in a mixed phase liquid-liquid system. The system can be a batch system, a semi-batch system, or a continuous system as is usual for aliphatic alkylation. Vigorous mixing is desirable to ensure good contact between the reactants and the catalyst.

[055] The isoparaffin and olefin can be introduced in the reactor separately or as a mixture, in one or multiple locations. The molar ratio of isoparaffin to olefin is generally 20:1 or less, or 15:1 or less, or 10:1 or less, or in a range of 2:1 to 20:1, or in a range of 2:1 to 15:1, or in a range of 2:1 to 10:1, or in a range 2:1 to 8:1, or in a range of 2:1 to 6:1, or in a range of 2:1 to 4:1, or in a range of 5:1 to 20:1, or in a range of 5:1 to 15:1, or in a range of 5:1 to 10:1.

[056] In a semi-batch system, the catalyst, optional co-catalyst, and at least a portion of the isoparaffin are introduced with no olefin present, followed by the olefin or a mixture of isoparaffin and olefin. In a semi-batch system, the olefin is added gradually over a period of time. The catalyst is measured in the reactor with respect to the amount of total olefins added over the course of the reaction, with a catalyst to olefin weight ratio in a range of from 0.1:1 to 10:1 (e.g., 0.2:1 to 5:1, or 0.5:1 to 2.5:1).

[057] In a continuous system, the ionic liquid catalyst, the isoparaffin, the olefin, and optionally the co-catalyst are each added continuously. Catalyst, optional co-catalyst, unreacted isoparaffin, and unreacted olefin are each removed continuously from the reaction zone along with alkylate product. The catalyst, co-catalyst, unreacted isoparaffin, and/or unreacted olefin may be recycled. The olefin may be added to one or more locations in the reaction zone. It is preferable to add the olefin to multiple locations in the reaction zone. Adding olefin in multiple locations or spreading the olefin addition over a longer period of time, results in the isoparaffin to olefin ratio measured in a specific location at a specific point in time to be higher. The isoparaffin to olefin ratio is defined as the cumulative amount of isoparaffin divided by the cumulative amount of olefin added across the entire reaction zone.

[058] Heat generated by the alkylation reaction can be removed using any of the methods known to those of skill in the art.

[059] Conjunct polymer forms as a by-product of the alkylation reaction. Conjunct polymers are typically highly conjugated, olefinic, highly cyclic hydrocarbons and have a strong affinity for the ionic liquid catalyst. The ionic liquid catalyst loses its effectiveness over time as the amount of conjunct polymer increases. Over time, the ionic liquid catalyst must then either be replaced or regenerated. Generally, only as much ionic liquid catalyst is regenerated as is necessary to maintain a desired level of catalyst activity. Generally, the alkylation process is operated at conditions sufficient to maintain a desired level of conjunct polymer in the ionic liquid. The amount of conjunct polymer in the ionic liquid during alkylation may be maintained at 10 wt. % or less (e.g., 9 wt. % or less, or 8 wt. % or less, or 7 wt. % or less, or 6 wt. % or less, or 5 wt. % or less, or 4 wt. %

or less, or 3 wt. % or less, or 2 wt. % or less, 1 wt. % or less). For example, the amount of conjunct polymer in the spent ionic liquid may be maintained in a range of from 0.5 wt. % to 10 wt. %, or 1 wt. % to 5 wt. %, or 2 wt. % to 4 wt. %. An amount of conjunct polymer in an ionic liquid phase can be measured using infrared spectroscopy, such as disclosed in U.S. Patent No. 9,290,702.

[060] At the reactor outlet, the hydrocarbon phase is separated from the ionic liquid phase by gravity settling based on density differences, or by other separation techniques known to those skilled in the art. Then the hydrocarbons are separated by distillation, and the starting isoparaffin which has not been converted is recycled to the reactor. The catalyst is typically recycled to the reactor as well.

[061] Typical alkylation conditions may include a temperature of from 30°C to 100°C, a pressure of from 300 psig to 700 psig (2068 kPa to 4826 kPa), an isoparaffin to olefin molar ratio of from 2:1 to 20:1, a residence time of from 5 minutes to 1 hour, an ionic liquid volume in the reactor of from 1 vol. % to 70 vol. %.

[062] The conversion of ethylene is typically at least 95% (e.g., at least 96%, or at least 97%, or at least 98%, or at least 99%). The percent ethylene conversion is defined as: (the amount of ethylene added to the reactor minus the amount of ethylene remaining after the reaction (or at the reactor outlet)) divided by the total amount of ethylene added to the reactor times 100. In a continuous process, ethylene conversion is defined as: (the amount of ethylene added to the reactor minus the total flow of ethylene out of the reactor) divided by the total flow of ethylene into the reactor.

[063] FIG. 1 illustrates one embodiment of an alkylation process according to the present disclosure. An isobutane feed stream **105**, an ethylene feed stream **110**, and an

ionic liquid catalyst composition stream **115**, optional co-catalyst, are fed to an alkylation zone **120**. The isobutane and the ethylene react in the presence of the ionic liquid catalyst composition to form alkylate.

[064] The effluent **125** from the alkylation zone **120** contains alkylate, unreacted isobutane, the ionic liquid catalyst, and possibly unreacted ethylene. The effluent **125** is sent to a separation zone **130** where it is separated into a hydrocarbon stream **135** comprising the alkylate and unreacted isobutane (and any unreacted ethylene) and an ionic liquid recycle stream **140**. Suitable separation zones include gravity settlers, coalescers, filtration zones comprising sand or carbon, adsorption zones, scrubbing zones, or combinations thereof.

[065] The hydrocarbon stream **135** is sent to a hydrocarbon separation zone **145** where it is separated into an alkylate stream **150** and an isobutane and co-catalyst recycle stream **155**. The alkylate stream **150** can be recovered and further treated as needed. The isobutane and co-catalyst recycle stream **155** can be recycled to the alkylation zone **120**, if desired. Suitable hydrocarbon separation zones include distillation or vaporization.

[066] The ionic liquid recycle stream **140** which typically contains some amount of conjunct polymer is also recovered from the separation zone **130** and can be recycled to the alkylation zone **120**, if desired. In some embodiments, at least a portion **160** of the ionic liquid recycle stream **140** can be sent to a regeneration zone **165** to remove at least some of the conjunct polymer from the ionic liquid to provide a regenerated ionic liquid recycle stream. The regenerated ionic liquid recycle stream **170** can be recycled to the alkylation zone **120**.

Alkylate

[067] In some aspects, the process can be used to upgrade low value C4 hydrocarbons to higher value alkylates. To that extent, one specific aspect is the alkylation of isobutane with ethylene to generate C6 compounds. Preferred products include isomers of dimethylbutane (DMB), namely, 2,3-dimethylbutane and 2,2-dimethylbutane. Other C6 isomers are also produced. One set competing isomers are methylpentanes (MP), namely 2-methylpentane and 3-methylpentane. The quality of the alkylate can be measured in the ratio of DMB to MP, with a high ratio desired (e.g., at least 7:1 or more, or at least 10:1 or more, or at least 12:1 or more, or at least 15:1 or more, or at least 20:1 or more).

[068] In some aspects, the alkylation reaction can have a selectivity for C6 of at least 65% or more, or at least 70% or more, or at least 75% or more. Selectivity for C6 is defined here as the total weight of products containing exactly six carbon atoms divided by the total weight of products containing five or more carbon atoms. In some aspects, the alkylate can have a mole ratio of dimethylbutane to methylpentane of at least 4:1 or more, or 7:1 or more, or at least 10:1 or more, or at least 15:1 or more, or at least 20:1 or more, or 25:1 or more, or 30:1 or more, or 35:1 or more.

[069] The alkylate may contain C8 paraffins. Preferred products include isomers of trimethylpentane (TMP), namely 2,2,3-trimethylpentane, 2,2,4-trimethylpentane, 2,3,3-trimethylpentane, and 2,3,4-trimethylpentane. Other C8 isomers are also produced. One set of competing isomers are dimethylhexanes (DMH), namely 2,2-dimethylhexane, 2,3-dimethylhexane, 2,4-dimethylhexane, 2,5-dimethylhexane, 3,3-dimethylhexane, and 3,4-dimethylhexane. The quality of the product stream can be measured in the ratio of total TMP to total DMH, with a higher ratio desired (e.g., of greater than

2:1, or greater than 3:1). C8 isomers may be present in an amount of 30 wt. % or less (e.g., 1 wt. % to 30 wt. %, or 5 wt. % to 15 wt. %) of the alkylate.

[070] The alkylate may contain C9+ paraffins. The C9+ paraffins may be present in an amount of less than 20 wt. % (e.g., less than 10 wt. %) of the alkylate.

[071] In some embodiments, the alkylate has a research octane number (RON) of 93 or more (e.g., 94 or more, 95 or more, 96 or more, 97 or more, 98 or more, 99, or 100 or more).

[072] The alkylate may have a bio-based carbon content (relative to the total mass of carbon in the alkylate), as determined by ASTM D6866-21, in a range having a lower limit selected from any of 1%, 5%, 10%, 15%, 20%, to an upper limit selected from any of 50%, 60%, 80%, 90%, and 100%, where any lower limit may be paired with any upper limit.

EXAMPLES

[073] The following illustrative examples are intended to be non-limiting.

EXAMPLE 1

Ionic Liquid Catalyst

[074] The ionic liquid catalyst used herein was N-butylpyridinium chloroaluminate, which was prepared according to U.S. Patent No. 7,495,144. Table 1 shows the chemical composition of the catalyst.

TABLE 1
Composition of the N-Butylpyridinium Chloroaluminate Ionic Liquid Catalyst

Element	Weight %
Al	12.4
Cl	56.5
C	24.6
H	3.2
N	3.3

EXAMPLES 2-5

Alkylation of Isobutane with Ethylene Using N-Butylpyridinium
Chloroaluminate Ionic Liquid Catalyst

[075] To a 100-1000 mL Parr autoclave reactor, isoparaffin feed controlled by a Quizix pump, olefin controlled by a Bronkhorst flow controller, HCl co-catalyst controlled by a Bronkhorst flow controller, and ionic liquid catalyst controlled by a LEWA pump were continuously fed. Both the hydrocarbon feed and HCl co-catalyst were fed to the top of the reactor while the ionic liquid was fed to the bottom of the reactor. The reactor contents were heated to a target temperature under a target pressure with overhead stirring. The target process conditions are shown in Examples. The reactor effluent was taken from the top of the reactor. The reactor effluent was separated in a downstream separator into a separate product phase and an ionic liquid catalyst phase. The product was analyzed by gas chromatography.

[076] Isobutane was obtained from a refinery FCC stream. The ethylene feed was Ultra-High Purity (UHP) grade ethylene purchased from Airgas. Table 2 shows the chemical composition of the isobutane and ethylene feeds.

TABLE 2
Composition of the Isobutane and Ethylene Feeds

<u>Isobutane Feed</u>	Weight %
Propane	6.3
Isobutane	79.9
n-Butane	12.4
Isopentane	1.4
<u>Ethylene Feed</u>	
Ethylene	99.9

[077] Table 3 shows conditions and results for isobutane alkylation with ethylene.

TABLE 3

Conditions and Results for Isobutane Alkylation with Ethylene

	Ex. 2	Ex. 3	Ex. 4	Ex. 5
<u>Alkylation Conditions</u>				
Temperature [°F]	140	120	100	90
Pressure [psig]	400	400	400	180
Isoparaffin/Olefin molar ratio	8	8	8	8
Ionic Liquid Content [vol. %]	10	10	10	10
Residence Time [min]	8	8	10	6
Olefin/HCl molar ratio	30	30	25	47
Ethylene Conversion [%]	98.0	96.0	99.7	38.0
<u>Alkylate Properties</u>				
<u>Cn Selectivity [%]</u>				
C5	0.9	2.9	7.0	2.4
C6	87.2	85.1	71.4	55.9
C7	1.1	1.4	4.2	3.0
C8	8.1	6.9	10.0	26.3
C9	0.3	0.8	2.1	3.0
C10	1.0	1.3	2.6	4.7
C11	0.7	0.6	1.7	3.5
C12+	0.8	1.0	1.0	1.2
<u>C6 Isomer Relative Distribution</u>				
2,2-Dimethylbutane	0	1	2	0.3
2,3-Dimethylbutane	97	96	78	97
2-Methylpentane	2	3	12	2.8
3-Methylpentane	1	1	5	0
Dimethylbutane/Methylpentane molar ratio	32.3	24.3	4.7	34.8
<u>C8 Isomer Relative Distribution [%]</u>				
Trimethylpentanes	70	68	53	47
Dimethylhexanes	21	19	34	50
Methylheptanes	8	11	12	3
<u>Octane Number</u>				
RON	101.0	100.4	94.3	96.8
MON	93.8	93.4	90.4	91.0
<u>SIMDIST (ASTM D2887) [°F]</u>				
T50	136	138	137	157
T90	192	193	227	285
T99	295	293	378	418
FBP (T99.5)	356	363	423	441

[078] The results show that alkylate produced from direct conversion of isobutane with ethylene by highly active ionic liquid catalyst contained predominantly C6 and C8

paraffins. Product selectivity to C6 alkylate (reaction product of 1 mole of ethylene and 1 mole of isobutane) and C8 alkylate (reaction product of 2 mole of ethylene and 1 mole of isobutane) can be controlled. Different amounts of C6 and C8 can be produced depending on process conditions selected. At low reaction temperature and lower reaction pressure (Example 5), the ethylene conversion was only 38% and a substantial amount of ethylene was unreacted. With carefully selected and controlled process conditions (Examples 2-4), high conversion of ethylene was achieved (>96%). This was surprising compared with the conventional C3 and C4 olefin alkylation processes where nearly 100% conversion of olefins with an ionic liquid catalyst is observed. This indicates that ethylene has lower reactivity compared with C3 and C4 olefins.

[079] As the reactor temperature was lowed from 140°F to 100°F (Examples 2 through 4), a decline in the RON octane number from 101 to 94 was observed. Again, this result is different from what is observed in C3 and C4 olefin alkylation processes where lower temperature provides alkylate with better RON octane number. It was very surprising to discover C8 isomer distribution as a function of temperature for ethylene alkylation is opposite that of C3 and C4 olefin alkylation. At lower reaction temperature, the dimethylhexane content in the C8 isomers significantly increased (e.g., as much as 50% in Example 5), and trimethylpentane content significantly decreased, resulting in poorer alkylate quality (lower octanes) for ethylene alkylation. For C3 and C4 olefin alkylation, lower reaction temperature increases the trimethylpentanes significantly, showing the opposite trend (Examples 8 vs. 9).

[080] This ethylene alkylation process chemistry is unique. Unlike C3 to C4 olefin alkylation processes, achieving ethylene conversion over 95% was very difficult and this can

be achieved only with highly active ionic liquid catalysts at carefully controlled process conditions.

EXAMPLE 6 (COMPARATIVE)

Alkylation of Isopentane with Ethylene Using N-Butylpyridinium Chloroaluminate Ionic Liquid Catalyst

[081] Alkylation of isopentane with ethylene using N-butylpyridinium chloroaluminate ionic liquid catalyst was carried in accordance with U.S. Patent No. 7,432,408.

[082] Conditions and results for isopentane alkylation with ethylene are shown in Table 5 below.

EXAMPLE 7 (COMPARATIVE)

Alkylation of Isobutane with C3/C4 Olefins Using N-Butylpyridinium Chloroaluminate Ionic Liquid Catalyst

[083] For Examples 7-9, refinery isobutane containing 85% isobutane and 15% n-butane was used after drying with 13X molecular sieve.

[084] A refinery olefin stream containing a mixture of C3 and C4 olefins (C3/C4 olefins) was dried with 13X molecular sieve and isomerized with a Pd/Al₂O₃ catalyst at 150°F, 250 psig in the presence of hydrogen to produce an isomerized C3/C4 olefin feed with the composition shown in Table 4.

Table 4
Composition of C3/C4 Olefin Feed

Component	Mol. %
Propane	13.3
Propylene	25.4
1-Butene	2.3
2-Butene	16.2
Isobutylene	6.7
n-Butane	12.4
Isobutane	22.2
C5+	1.6

[085] Evaluation of C3/C4 olefin alkylation with isobutane was performed in a continuously stirred tank reactor. An 8:1 molar mixture of isobutane and olefin was fed to the reactor with vigorous stirring. Ionic liquid catalyst (N-butylpyridinium chloroaluminate) was fed to the reactor via a second inlet port targeting to occupy 6 vol. % in the reactor. A small amount of n-butyl chloride was added to produce anhydrous HCl gas. The average residence time (combined volume of feeds and catalyst) was about 12 minutes. The outlet pressure was maintained at 200 psig and the reactor temperature was maintained at 95°F (35°C) using external cooling.

[086] The reactor effluent was separated with a coalescing separator into a hydrocarbon phase and an ionic liquid catalyst phase. The hydrocarbon stream was further separated into multiple streams with three distillation columns: a gas stream containing C3- hydrocarbons, an n-C4 stream, an i-C4 stream and an alkylate stream. The ionic liquid catalyst was recycled back to the alkylation reactor for repeated use. To maintain the activity of the ionic liquid catalyst, a fraction of used ionic liquid catalyst was sent to a hydrogenation reactor for a reduction of the amount of conjunct polymer in the ionic liquid catalyst. The amount of conjunct polymer in the ionic liquid catalyst was maintained in a range of from 2-6 % to obtain good quality alkylate gasoline. The amount of conjunct polymer in the ionic liquid catalyst was determined by Fourier transform infrared (FT-IR) spectroscopy in accordance with U.S. Patent No. 9,290,702.

[087] Table 5 shows conditions and results for isobutane alkylation with C3/C4 olefins.

EXAMPLES 8-9 (COMPARATIVE)

Alkylation of Isobutane with C4 Olefins Using N-Butylpyridinium Chloroaluminate Ionic Liquid Catalyst

[088] Alkylation was carried out as described in Examples 2-5 except that the olefin was a mixture of C4 olefins.

[089] Table 5 shows conditions and results for isobutane alkylation with C4 olefins.

TABLE 5
Conditions and Results for Isoparaffin-Olefin Alkylation

	Ex. 2	Ex. 6	Ex. 7	Ex. 8	Ex. 9
Olefin Feed	C2	C2	C3/C4	C4	C4
Isoparaffin Feed	i-C4	i-C5	i-C4	i-C4	i-C4
Alkylation Conditions					
Temperature [°F]	140	122	95	95	50
Pressure [psig]	400	300	200	150	150
Isoparaffin/Olefin mole ratio	8	4	8	8	8
Ionic Liquid Content [vol. %]	10	15	6	4	5
Residence Time [min]	8	40	12	4	5
Olefin/HCl mole ratio	30	—	60	49	40
Olefin Conversion [%]	98.0	95.0	100	100	100
Alkylate Properties					
Cn Selectivity [%]					
C5	0.9	4.1 ^(a)	—	4.5	6.0
C6	87.2	8.0	—	6.3	6.9
C7	1.1	63.3	—	7.0	5.2
C8	8.1	9.1	—	66.4	65.0
C9	0.3	7.1	—	9.2	8.3
C10	1.0	4.2	—	3.1	4.6
C11	0.7	4.3 ^(b)	—	3.2	3.1
C12+	0.8	—	—	0.2	0.9
C8 Isomer Distribution [%]					
Trimethylpentanes	70	—	—	81	87
Dimethylhexanes	21	—	—	17	9
Octane Number					
RON	101	87	89	95	97
MON	93.8	84	86	92.2	93.4
SIMDIST (ASTM D2887) [°F]					
FBP (99.5)	356	—	—	376	378

^(a) C5-.

^(b) C11+.

[090] The results presented in Tables 3 and 5 show that ethylene alkylation at relatively higher reaction temperatures (e.g., 100°F and above) provided very high olefin conversion ($\geq 96.0\%$) and generated alkylate with high octane numbers (Examples 2 and 3 vs. 4 and 5). This result is contrary to conventional C4 olefin alkylation, where a relatively lower temperature (e.g., less than 100°F) provided 100% conversion and high octane numbers (Examples 8 and 9). The dimethylhexane contents in the C8 fraction was only 17% and 9% at 95 and 50°F, respectively. For ethylene alkylation, the dimethylhexane content in C8 isomers significantly increased as the reaction temperature is lowered, as much as 50% at 90°F (Table 3). For C3 and C4 olefin alkylation, lower reaction temperature increases the tri-methyl-pentanes significantly, the opposite trend (Examples 8 vs. 9). Again, this result is contrary to conventional C4 olefin alkylation.

CLAIMS

1. A process for making an alkylate, the process comprising:
(a) dehydrating a bioethanol feed to form an impure bio-ethylene mixture;

(b) recovering a bio-ethylene stream from the impure bio-ethylene mixture; and

(c) passing an isobutane feed stream and the bio-ethylene stream to an alkylation reactor, wherein the alkylation reactor contains an ionic liquid, the ionic liquid comprising an organic cation and a halometallate anion, for reacting the isobutane and bio-ethylene to generate an alkylate having a research octane number (RON) of 93 or more;

wherein the alkylation reactor is operated at reaction conditions including a temperature of from 30°C to 100°C, a pressure of from 300 psig to 700 psig (2068 kPa to 4826 kPa), an overall paraffin to olefin molar ratio from 2 to 20, and a residence time of from 5 minutes to 1 hour.

2. The process of claim 1, wherein the bioethanol feed is an azeotropic ethanol-water mixture obtained from a bioethanol production plant.

3. The process of claim 1, wherein dehydrating comprises contacting the bioethanol feed with an acid catalyst under dehydration conditions to form ethylene and water.

4. The method of claim 3, wherein the acid catalyst is selected from the group consisting of a metal oxide catalyst, a molecular sieve catalyst, and a heteropolyacid catalyst.

5. The process of claim 3, wherein the dehydration conditions include a temperature of in a range of from 150°C

to 500°C, a pressure in a range of from 100 to 2000 kPa, and a weight hourly space velocity in a range of from 0.5 to 10 h⁻¹.

6. The process of claim 1, wherein the organic cation of the ionic liquid comprises an ammonium cation, a pyrrolidinium cation, a pyridinium cation, an imidazolium, a phosphonium cation, or a combination thereof.

7. The process of claim 1, wherein the halometallate anion comprises a metal selected from Al, Ga, In, Mn, Fe, Co, Ni, Cu, Zn, or a combination thereof, and a halide selected from F, Cl, Br, I, or a combination thereof.

8. The process of claim 1, wherein the halometellate anion is a haloaluminate anion.

9. The process of claim 1, wherein the ionic liquid is present in an amount of from 1 vol. % to 70 vol. % of a total volume of material in the alkylation reactor.

10. The process of claim 1, wherein the process has a selectivity for C6 of at least about 70%, and the alkylate has a mole ratio of dimethylbutane to methylpentane of greater of at least 10.

11. The process of claim 1, wherein the alkylation reactor further comprises a co-catalyst.

12. The process of claim 11, wherein the co-catalyst comprises a Brønsted acid selected from the group consisting of HCl, HBr, HI, and mixtures thereof, or a Brønsted acid precursor.

13. The process of claim 1, wherein a conversion of the bio-ethylene is at least 95%.

14. The process of claim 1, wherein the alkylate has a RON of 94 or more, or 95 or more, or 96 or more, or 97 or more, or 98 or more, or 99 or more, or 100 or more.

15. The process of claim 1, wherein the temperature in the alkylation reactor is in a range of from 35°C to 70°C.

16. The process of claim 1, wherein the pressure in the alkylation reactor is in a range of from 350 psig to 500 psig (2413 kPa to 3447 kPa).

17. The alkylation process of claim 1 further comprising:
separating the alkylate and unreacted isobutane feed from the ionic liquid to form a hydrocarbon stream comprising the alkylate and the unreacted isobutane feed and an ionic liquid stream comprising the ionic liquid;
separating the hydrocarbon stream into an alkylate stream and an unreacted isobutane stream; and
recycling at least one of the unreacted isobutane stream and the ionic liquid stream.

18. The process of claim 17, further comprising:
regenerating at least a portion of the ionic liquid in the ionic liquid stream; and
recycling the regenerated ionic liquid catalyst to the alkylation reactor.

19. An alkylate having a research octane number (RON) of 93 or more, comprising:

(i) at least 70 wt. % C6 paraffins, wherein the C6 paraffins comprise isomers of dimethylbutane (DMB) and

methylpentane (MP) and a molar ratio of DMB to MP is at least 7:1;

(ii) 30 wt. % or less C8 paraffins; and

(iii) less than 20 wt. % C9+ paraffins;

wherein the alkylate has a bio-based carbon content in a range of from 1% to 100%, according to ASTM D6866-21.

20. The alkylate of claim 19, having a RON of at least 94 or more, or 95 or more, or 96 or more, or 97 or more, or 98 or more, or 99 or more, or 100 or more.

21. The alkylate of claim 19, comprising at least 80 wt. % C6 paraffins.

22. The alkylate of claim 19, comprising 5 wt. % to 15 wt. % C8 paraffins.

23. The alkylate of claim 19, comprising less than 10 wt. % C9+ paraffins.