

BENZENE ALKYLATION

FIELD OF THE DISCLOSURE

[0001] Embodiments disclosed herein relate generally to processes for the production of alkylbenzenes, such as ethylbenzene and cumene, among others.

BACKGROUND

[0002] Ethylbenzene and cumene are currently produced by the reaction of benzene and the respective olefin, i.e., ethylene and propylene by acid catalysis. More recently, benzene alkylation processes have used the corresponding alcohols as an alkylating agent. Cumene, also known as isopropylbenzene, is useful for the production of phenol, acetone, and alphas-methylstyrene. Ethylbenzene is useful in the production of styrene. Alkyl-substituted aromatics also are useful as high octane transportation fuels. Various processes for their manufacture are known.

[0003] The existing processes for producing ethylbenzene and cumene inherently produce polyalkylated species as well as the desired monoalkylated product. It is therefore typical practice to transalkylate the polyalkylated species with benzene to produce additional alkylbenzene either by recycling the polyalkylated species to the alkylation reactor or by feeding the polyalkylated species to a separate transalkylation reactor. However, the addition of a separation train or a stand-alone transalkylation reactor adds significantly to process complexity, piece count, operating and capital costs.

SUMMARY OF THE CLAIMED EMBODIMENTS

[0004] It has been found that processes for alkylating benzene with an alcohol may be improved by integrating the systems of distillation, catalytic alkylation, and catalytic transalkylation. For example, a catalytic distillation reactor system may be used to produce ethylbenzene from ethanol and benzene. Benzene may be mixed with the reflux stream and fed to the top of the column. Fresh ethanol, unreacted ethanol, diethyl ether by-product (also an alkylating agent), and optionally a portion of the recovered benzene and/or polyalkylated benzene may be fed to the column between the alkylation catalyst, located in the upper portion of the column, and the transalkylation catalyst, located in the lower portion of the column. In this manner, the three systems of distillation, alkylation, and transalkylation may be consolidated

into a single column, eliminating at least one major reactor from the conventional configuration for producing ethylbenzene. Cumene and other alkylated benzene species may be produced in a similar manner using the corresponding alcohols.

[0005] In one aspect, embodiments disclosed herein relate to a process for the production of alkylbenzene, the process including: feeding a C₁ to C₆ alcohol and benzene to a catalytic distillation reactor system comprising an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst; concurrently in the catalytic distillation reactor system: reacting a portion of the alcohol with the benzene within the upper reaction zone to form a reaction mixture containing water, alkylbenzene, dialkyl ether, unreacted alcohol, unreacted benzene, and polyalkylate including dialkylbenzene; reacting a portion of the polyalkylate with benzene in the lower reaction zone to form additional alkylbenzene; and fractionally distilling the reaction mixture; recovering an overheads fraction from the catalytic distillation reactor system comprising benzene, unreacted alcohol, water, and dialkyl ether; recovering a bottoms fraction from the catalytic distillation reactor system comprising benzene, alkylbenzene, and polyalkylate.

[0006] In another aspect, embodiments disclosed herein relate to a process for the production of ethylbenzene, the process including: feeding ethanol and benzene to a catalytic distillation reactor system comprising an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst; concurrently in the catalytic distillation reactor system: reacting a portion of the ethanol with the benzene within the upper reaction zone to form a reaction mixture containing water, ethylbenzene, diethyl ether, unreacted ethanol, unreacted benzene, and polyalkylate including diethylbenzene; reacting a portion of the polyalkylate with benzene in the lower reaction zone to form additional ethylbenzene; and fractionally distilling the reaction mixture; recovering an overheads fraction from the catalytic distillation reactor system comprising benzene, ethanol, water, and diethyl ether; recovering a bottoms fraction from the catalytic distillation reactor system comprising benzene, ethylbenzene, and polyalkylate; condensing and phase separating the overheads fraction to form a first liquid fraction comprising benzene and a second liquid fraction comprising the water, ethanol, and diethyl ether; separating the bottoms fraction from

the catalytic distillation reactor system in a first distillation column to recover an overheads fraction comprising benzene and a bottoms fraction comprising ethylbenzene and polyalkylate; feeding at least a portion of the first liquid fraction to the catalytic distillation reactor system as a reflux; separating the second liquid fraction in a second distillation column to recover an overheads fraction comprising ethanol and diethyl ether and a bottoms fraction comprising water; feeding the ethanol feed and at least a portion of the overheads fraction from the second distillation column to the catalytic distillation reactor system intermediate the upper and lower reaction zones.

[0007] In another aspect, embodiments disclosed herein relate to a process for the production of cumene, the process including: feeding isopropanol and benzene to a catalytic distillation reactor system comprising an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst; concurrently in the catalytic distillation reactor system: reacting a portion of the isopropanol with the benzene within the upper reaction zone to form a reaction mixture containing water, cumene, diisopropyl ether, unreacted isopropanol, unreacted benzene, and polyalkylate including diisopropylbenzene; reacting a portion of the polyalkylate with benzene in the lower reaction zone to form additional cumene; and fractionally distilling the reaction mixture; recovering an overheads fraction from the catalytic distillation reactor system comprising benzene, isopropanol, water, and diisopropyl ether; recovering a bottoms fraction from the catalytic distillation reactor system comprising benzene, cumene, and polyalkylate; condensing and phase separating the overheads fraction to form a first liquid fraction comprising benzene and a second liquid fraction comprising the water, isopropanol, and diisopropyl ether; separating the bottoms fraction from the catalytic distillation reactor system in a first distillation column to recover an overheads fraction comprising benzene and a bottoms fraction comprising cumene and polyalkylate; feeding at least a portion of the first liquid fraction to the catalytic distillation reactor system as a reflux; separating the second liquid fraction in a second distillation column to recover an overheads fraction comprising isopropanol and diisopropyl ether and a bottoms fraction comprising water; feeding the isopropanol feed and at least a portion of the overheads fraction

from the second distillation column to the catalytic distillation reactor system intermediate the upper and lower reaction zones.

[0008] Other aspects and advantages will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0009] Figure 1 is a simplified process flow diagram of a process for the alkylation of benzene according to embodiments disclosed herein.

[0010] Figure 2 is a simplified process flow diagram of a process for the alkylation of benzene according to embodiments disclosed herein.

[0011] Figure 3 is a simplified process flow diagram of a portion of a process for the alkylation of benzene according to embodiments disclosed herein.

[0012] Figure 4 is a simplified process flow diagram of a process for the alkylation of benzene according to embodiments disclosed herein.

[0013] Figure 5 is a simplified process flow diagram of a process for the alkylation of benzene according to embodiments disclosed herein.

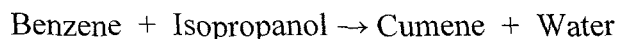
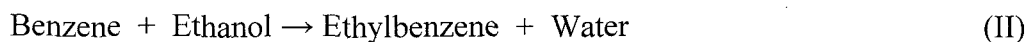
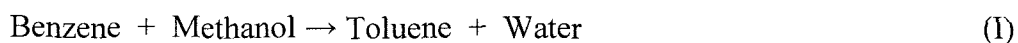
DETAILED DESCRIPTION

[0014] Within the scope of this application, the expression “catalytic distillation reactor system” denotes an apparatus in which the catalytic reaction and the separation of the products take place at least partially simultaneously. The apparatus may comprise a conventional catalytic distillation column reactor, where the reaction and distillation are concurrently taking place at boiling point conditions, or a distillation column operatively connected with at least one side reactor to which a side draw from the distillation column is introduced as a feed and from which a reactor effluent is withdrawn and returned to the distillation column, where the side reactor may be operated as a liquid phase reactor, a vapor phase reactor, or a boiling point reactor. While both catalytic distillation reactor systems described may be preferred over conventional liquid phase reaction followed by separations, a catalytic distillation column reactor may have the advantages of decreased piece count, reduced capital cost, efficient heat removal (heat of reaction may be absorbed into the heat of vaporization of the mixture), and a potential for shifting equilibrium. Divided wall distillation columns, where at least one section of the divided wall column contains a

catalytic distillation structure, may also be used, and are considered “catalytic distillation reactor systems” herein.

[0015] Processes disclosed herein may include any number of reactors, including catalytic distillation reactor systems, both up-flow and down-flow. Use of catalytic distillation reactor systems may prevent foulants and heavy catalyst poisons in the feed from contacting the catalyst. In addition, clean reflux may continuously wash the catalyst zone. These factors combine to provide a long catalyst life. The heat of reaction evaporates liquid and the resulting vapor is condensed in the overhead condenser to provide additional reflux. The natural temperature profile in the fractionation column results in a virtually isothermal catalyst bed rather than the temperature increase typical of conventional fixed bed reactors.

[0016] In one aspect, embodiments herein relate to processes for the production of alkylbenzenes, such as ethylbenzene and cumene, among others. Alkylation of benzene with an alcohol may be represented by the following reactions. Alkylation of benzene with other alcohols may proceed in a similar manner, producing water and the corresponding alkylate.



(III)

If desired, alkylation of toluene may be effected in a similar manner.

[0017] Production of alkylbenzene via catalytic distillation may be attained by feeding a C₁ to C₈ alcohol and benzene to a catalytic distillation reactor system including an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst. For example, the upper reaction zone may be located in the rectifying section of the column and the lower reaction zone may be located in the stripping portion of the column.

[0018] In the catalytic distillation reactor system, at least a portion of the benzene and alcohol distills upward within the column and the benzene may be reacted with the alcohol over the alkylation catalyst to produce an alkyl benzene and water. The alcohol may also react with itself to form a dialkyl ether. Additionally, alkyl benzene may be further alkylated over the alkylation catalyst to produce dialkyl benzene,

trialkyl benzene, and higher polyalkylated benzenes. The alkylbenzene and polyalkylate produced in the upper reaction zone may then traverse downward through the column, for contact with the transalkylation catalyst and recovery of the alkylbenzene and polyalkylate as a bottoms fraction. Benzene present in the lower reaction zone is available for transalkylation with the polyalkylate, producing additional monoalkylate. Additionally, benzene may react with the alcohol or the dialkyl ether over the transalkylation catalyst, also producing additional monoalkylate.

[0019] Concurrent with the above described reactions, the feed components and reaction products are separated (fractionally distilled) within the catalytic distillation reactor system. Benzene, unreacted alcohol, water, and dialkyl ether may be recovered from the column as an overheads product, and benzene, alkylbenzene, and polyalkyl benzene may be recovered as a bottoms fraction.

[0020] The operation of the catalytic distillation column should be such that reaction conditions suitable for the alkylation of benzene with an alcohol are achieved in the reaction zones. In some embodiments, the reaction zones may be maintained at a temperature in the range from 200°F to 700°F; from 200°F to 400°F in other embodiments.

[0021] The mole ratio of alcohol to benzene fed to the reactor may range from 0.1:1 to 10:1 in some embodiments; from 0.5:1 to 5:1 in other embodiments; from 0.8:1 to 2:1 in other embodiments; and from 0.9:1 to 1.1:1 in other embodiments.

[0022] Alcohols useful in embodiments disclosed herein may include C₁ to C₆ primary and secondary alcohols. Examples of alcohols useful in embodiments disclosed herein include methanol, ethanol, n-propanol, i-propanol, n-butanol, i-butanol and t-butanol, among others.

[0023] Any catalyst useful for the alkylation and/or transalkylation of benzene with an alcohol may be used in the processes disclosed herein. For example, molecular sieves or zeolitic catalysts may be useful for the alkylation and/or transalkylation of benzene. Molecular sieves useful in embodiments disclosed herein may include porous, crystalline, three-dimensional alumina-silicates of the zeolite mineral group. The crystal skeleton is composed of silicon and aluminum atoms each surrounded by four oxygen atoms to form. The term molecular sieve can be applied to both naturally occurring zeolites and synthetic zeolites. Naturally occurring zeolites have irregular

pore size and are not generally considered as equivalent to synthetic zeolites. Amorphous forms of synthetic silicas and aluminas may also be used.

[0024] Synthetic zeolites are typically prepared in the sodium form, wherein a sodium cation is in close proximity to each aluminum tetrahedron and thereby balancing its charge. To date, seven principal types of molecular sieves have been reported, namely A, X, Y, L, erionite, omega and mordenite. The type A zeolite has relatively small effective pore size (diameter). Types X and Y have larger pore size and differ with regard to the ratio of Al_2O_3 to SiO_2 . The type L zeolite has a higher ratio of Al_2O_3 to SiO_2 .

[0025] In a family of embodiments, catalysts useful in the processes disclosed herein may contain a zeolite sometimes referred to as medium pore or ZSM-5 type. In other embodiments, the zeolite may be a medium pore shape selective acidic metallosilicate zeolite selected from the group consisting of ZSM-5, H-ZSM-5, ZSM-11, ZSM-12, ZSM-22, ZSM-23, ZSM-35, ZSM-50, MCM-22, as well as larger pore zeolite Y and zeolite Beta. In a family of embodiments, a particular catalyst found to effectively facilitate alkylation and/or transalkylation of benzene is zeolite beta in proton form.

[0026] Other catalysts useful in embodiments disclosed herein may include phosphorous-modified zeolites, aluminas, and silicas. For example, one particular catalyst useful in embodiments disclosed herein is AlPO_4 . In another embodiment, the AlPO_4 may be supported on alumina.

[0027] To facilitate fractionation and catalytic activity, the above described catalysts may be prepared in the form of a distillation structure. The catalytic distillation structure must be able to function as catalyst and as mass transfer medium. The catalyst must be suitably supported and spaced within the column to act as a catalytic distillation structure.

[0028] In some embodiments, the catalyst is contained in a structure as disclosed in U.S. Patent No. 5,730,843, which is hereby incorporated by reference. In other embodiments, one or more of the above-described catalysts may be contained in a plurality of wire mesh tubes closed at either end and laid across a sheet of wire mesh fabric such as demister wire. The sheet and tubes are then rolled into a bale for loading into the distillation column reactor. This embodiment is described, for example, in U.S. Patent No. 5,431,890, which is hereby incorporated by reference. Other useful catalytic distillation structures are disclosed in U.S. Patent Nos.

4,302,356, 4,443,559, 4,731,229, 5,073,236, 5,431,890, 5,266,546, and 5,730,843, which are each incorporated by reference.

[0029] As mentioned above, dialkyl ether may be formed as a byproduct via alcohol dehydration over the alkylation catalyst. Dialkyl ether is an alkylating agent, and may react with benzene to form alkylbenzene over the alkylation and/or transalkylation catalysts. Any dialkyl ether recovered in the column overheads may be recycled to the column for reaction with benzene. In this manner, dialkyl ether formation may be balanced by the dialkyl ether consumption, resulting in no net dialkyl ether production.

[0030] Referring now to Figure 1, a simplified process flow diagram for the production of alkyl benzene according to embodiments disclosed herein is illustrated. Fresh alcohol feed is introduced to catalytic distillation reactor system 10 via flow line 12. Fresh benzene is introduced to catalytic distillation reactor system 10 via flow line 14. In some embodiments, benzene may additionally be added via separate stream(s) (not illustrated) to catalytic distillation reactor system 10, such as when additional benzene or localized benzene flow may be beneficial to the optimization of column operations. Catalytic distillation reactor system 10 includes an upper reaction zone 16 containing a bed of alkylation catalyst and a lower reaction zone 18 containing a bed of transalkylation catalyst.

[0031] In the upper reaction zone 16, benzene and alcohol are contacted with the alkylation catalyst and react to form alkyl benzene, water, and byproducts, such as dialkyl benzene, trialkylbenzene, and other polyalkylate products, as well as dialkyl ether, formed by the dehydration of the alcohol over the alkylation catalyst. The rectifying section of the column (above the alcohol feed) also separates the alkylbenzene and polyalkyl benzene from unreacted benzene, unreacted alcohol, water, and dialkyl ether, which may be recovered from catalytic distillation reactor system 10 as an overheads fraction via flow line 20.

[0032] In the lower reaction zone 18, benzene may be alkylated with dialkyl ether and/or alcohol. Additionally, benzene may react with polyalkylated benzene to form additional monoalkylate. The stripping section of the column (below the alcohol feed) also provides for the separation of the light components (water, alcohol, dialkyl ether) from the alkylbenzene product. Unreacted benzene, the alkylbenzene and

polyalkyl benzenes may be recovered from catalytic distillation reactor system 10 as a bottoms fraction via flow line 22.

[0033] In Figure 1, the catalytic distillation reactor system 10 is operated downflow with respect to benzene. In this case, the fresh benzene, which may also be mixed with various recycle streams, serves as the reflux feed to catalytic distillation reactor system 10. In other embodiments, flow line 14 may be a reflux feed, returning a portion of the overheads to the column, and the fresh benzene may be introduced at a lower feed point, such as intermediate the upper and lower reaction zones, among other possible locations.

[0034] Figure 1 is also described as feeding the alcohol to the catalytic distillation reactor system 10 intermediate the upper and lower reaction zones. In some embodiments, two or more alcohol feeds may be used, introducing the alcohol along the length of the column. In this manner, an area of high alcohol concentration in the column may be avoided, *thereby limiting the extent of the dehydration reaction*. The fresh alcohol fed to the column may also be mixed with various recycle streams, embodiments of which are described below.

[0035] Referring now to Figure 2, a simplified process flow diagram of a process for the production of alkylbenzene according to embodiments disclosed herein is illustrated, where like numerals represent like parts. The general flow scheme as described with respect to Figure 1 is used, where fresh benzene is fed to the top of the column via flow line 14, along with recycle components, and fresh alcohol is fed between the upper and lower reaction zones via flow line 12, along with recycle components.

[0036] The bottoms fraction recovered from catalytic distillation reactor system 10 via flow line 22 may include benzene, alkyl benzene, and polyalkyl benzene, including dialkyl benzene, trialkyl benzene, and higher alkylated benzenes. The bottoms fraction may then be fed to a first separation column 24, for separating the benzene from the alkylbenzene and the polyalkyl benzene. The benzene may be recovered as an overheads fraction from first separation column 24 via flow line 26. The recovered benzene may then be recycled via flow line 26 back to catalytic distillation reactor system 10 for additional pass(es) through the reaction zones.

[0037] The alkylbenzene and polyalkyl benzene may be recovered as a bottoms fraction from first separation column 24 via flow line 28. The alkylbenzene and

polyalkyl benzene may then be fed to second separator 30 for separating the alkylbenzene from the polyalkyl benzene. As illustrated in Figure 2, the alkylbenzene may be recovered as an overheads fraction from second separator 30 via flow line 32, dialkyl benzene or dialkyl benzene and trialkylbenzene may be recovered from second separator 30 as a side draw fraction via flow line 34, and heavier polyalkylate may be recovered from second separator 30 as a bottoms fraction via flow line 36. If desired, the side draw fraction may be recycled back to catalytic distillation reactor 10 for continued reaction with benzene in the lower portion of the column to produce additional alkylbenzene.

[0038] The overheads fraction recovered from catalytic distillation reactor system 10 via flow line 20 may include benzene, alcohol, dialkyl ether, and water. The overheads fraction may then be condensed and phase separated, such as via indirect heat exchanger and settling drum 40. To achieve adequate liquid-liquid separation, it may be necessary to cool the condensate to a temperature of about 50°C or less. Phase separation may result in an upper hydrocarbon liquid fraction, which may include benzene as well as some dialkyl ether and/or alcohol, and a lower aqueous fraction, which may include water, alcohol, and dialkyl ether. The upper liquid fraction, primarily benzene, may be recovered from drum 40 via flow line 42, a portion of which may be recycled to the column with the fresh benzene as reflux, and a portion of which may be recycled to the column with the fresh alcohol feed. Thus, as illustrated, the column reflux line 44 includes fresh benzene, recycle benzene from first separator 24, and recycle benzene from drum 40.

[0039] The lower liquid fraction, including water, alcohol, and dialkyl ether, may be recovered from drum 40 via flow line 46 and fed to third separator 48 for separating the water from the alcohol and the dialkyl ether. Water may be recovered from third separator 48 as a bottoms fraction via flow line 50, and may be treated or disposed as necessary. Alcohol and dialkyl ether may be recovered from third separator 48 as an overheads fraction via flow line 52 and recycled back to catalytic distillation reactor system 10 via flow line 54 for continued reaction. Thus, as illustrated, the column feed line 56 includes fresh alcohol feed, recycle benzene from drum 40, recycle alcohol and dialkyl ether from third separator 48, and recycle polyalkyl benzene from second separator 30.

[0040] Separation of the water, dialkyl ether, and alcohol in third separator 48 may result in the overheads fraction containing some water. For example, where the ternary system forms an azeotrope, water may be carried over in the overheads recovered via flow line. To limit the amount of water recycled to catalytic distillation reactor system 10, a separation system as illustrated in Figure 3 may be used. The aqueous fraction recovered from drum 40 via flow line 46 is fed to third separator 48 for separation as described above. In this embodiment, the overheads fraction recovered via flow line 52 may include water, alcohol and dialkyl ether. The overheads fraction may then be mixed with a benzene-containing stream 58, such as a portion or all of the fresh benzene stream 14, a portion or all of the benzene recovered from first separator 24 via flow line 26, or a portion or all of the upper liquid fraction recovered from drum 40 via flow line 42, or a mixture of two or more of these streams or portions thereof. The resulting mixture may then be phase separated in drum 60 to recover a hydrocarbon fraction via flow line 62, including the benzene, alcohol, and dialkyl ether, and an aqueous water fraction via flow line 64. The aqueous fraction may include some alcohol and dialkyl ether, and may be recycled to third separator 48 for continued separation and recovery of the alcohol and dialkyl ether.

[0041] Referring now to Figure 4, a simplified process flow diagram of a process for the production of alkylbenzene according to embodiments disclosed herein is illustrated, where like numerals represent like parts. In this embodiment, the fresh benzene feed and the fresh alcohol feed are introduced intermediate the upper and lower reaction zones 16, 18 and reacted/distilled as described with respect to Figure 1. The overheads fraction recovered from catalytic distillation reactor system 10 via flow line 20 is condensed and phase separated via indirect heat exchanger 38 and drum 40, as described above. The lower liquid fraction recovered via flow line 46 is fed to separator 48, and separated as described in Figure 3. As illustrated, the benzene mixed with the overheads fraction from third separator 48 fed to drum 60 includes both the fresh benzene 14 and the recycle benzene recovered as an overheads from first separator 24 via flow line 26.

[0042] A portion of the upper liquid fraction recovered via flow line 42 is fed to catalytic distillation reactor system 10 as reflux via flow line 70. The remaining portion of the upper liquid fraction is combined with the hydrocarbon fraction

recovered from drum 60 via flow line 62 and the fresh alcohol feed fed via flow line 12 for introduction as the column feed via flow line 56.

[0043] The bottoms fraction recovered from the catalytic distillation reactor system 10 via flow line 22 may be processed as described above, recovering and recycling dialkyl benzene as a side draw for recycle to the column. Optionally, alkylbenzene may be recovered as an overheads via flow line 32, and the polyalkylate, inclusive of the dialkyl benzene and trialkyl benzene may be recovered from second separator 30 as a bottoms fraction via flow line 72. The polyalkylate may then be subsequently processed, separated, or used as a fuel blendstock, as may be appropriate for the production facility.

[0044] Referring now to Figure 5, a simplified process flow diagram of a process for the production of alkylbenzene according to embodiments disclosed herein is illustrated, where like numerals represent like parts. The overheads fraction recovered from catalytic distillation reactor system 10 is processed similar to that as described with respect to Figure 4, where a portion of the upper liquid fraction 42 is used as column reflux 70, and fresh benzene 14 is combined with the overheads 52 from third separator 48 to limit the amount of water recycled to catalytic distillation reactor system 10.

[0045] In this embodiment, catalytic distillation column 10 is maintained under operating conditions to result in the bottoms fraction recovered via flow line 22 containing less than 0.03 wt.% benzene. The bottoms fraction may then be fed directly to separator 30 for separation of the alkylbenzene, recovered as an overheads fraction via flow line 32, from the polyalkyl benzene, recovered as a bottoms fraction 36. As described with Figure 2, if desired, a side draw fraction may be recovered from column 30 via flow line 34, the side draw containing dialkyl benzene and trialkyl benzene, which may be recycled to catalytic distillation reactor system 10 for production of additional alkyl benzene. Where the bottoms fraction contains a sufficiently low concentration of benzene, the resulting alkylbenzene product stream 32 may have a purity of at least 99.95 wt.% alkylbenzene.

[0046] It has also been found that significant reductions in utility requirements may be achieved with the integrated distillation, alkylation, and transalkylation system described herein. For example, reducing the temperature of the overheads fraction recovered from catalytic distillation reactor system 10 may be achieved by contacting

the overheads fraction in indirect heat exchange with the bottoms fraction recovered from third separator 48 via flow line 50, the overhead fraction recovered from second separator 24 via flow line 26. Additionally, the overhead fraction may be contacted in indirect heat exchange with water/steam for the production of warm water or low or medium pressure steam, which may be used elsewhere in the process, such as for indirect heat exchange to condense the overhead fraction recovered from third separator 48 via flow line 52. The lower liquid fraction recovered from drum 40 via flow line 46 may also be heated prior to feed to third separator 48 using the bottoms fraction recovered from third separator 48 via flow line 50. Using heat integration in this manner may effectively minimize or negate the need for cooling water and may result in the utilization of all the heat generated in the process due to the exothermic alkylation reaction.

[0047] As described above, embodiments disclosed herein provide for the production of ethylbenzene, cumene, and other alkyl benzenes via a catalytic distillation process integrating the systems of distillation, catalytic alkylation, and catalytic transalkylation. Advantageously, embodiments disclosed herein may provide for one or more of the following advantages as compared to a conventional process configuration for producing alkyl benzenes:

- Reduction in the energy consumption by up to 45% over convention ethanol-based or current commercial ethylene-based alkylation processes. Specifically, the catalytic distillation reactor system reboiler and condenser duties may be reduced by up to 50%, benzene recovery column duty may be reduced by up to 50%, benzene recovery column condenser duty may be reduced by up to 40%, and the present system negates the need for a transalkylation feed heater.
- Equipment piece count is reduced, and capital costs may be reduced by up to 60% over current commercial ethylene-based alkylation processes. Specifically, the following major equipment pieces may be eliminated from the process: (1) a finishing reactor, (2) a transalkylation reactor, (3) a diethylbenzene/triethylbenzene column, (4) a light end stripper, (5) a vent absorber, (6) an ethylene compressor, and (7) all auxiliary equipment such as pumps, reboilers, condensers, drums, and control systems associated with items (1) through (6).

- Electricity consumption may be reduced by more than 50% as compared to current commercial ethylene-based alkylation processes. Specifically, the number of pumps required is reduced by more than half and a compressor is not required.
- Cooling water usage may be reduced by up to 100%, and cooling water used may be utilized to generate low pressure steam effectively.
- The size of downstream equipment may be reduced.
- Catalyst consumption and cycle times are enhanced over fixed bed processes, which are limited due to coking and poisoning. In the catalytic distillation reactor system, the catalyst may be consistently washed and cleaned due to the liquid traffic in the column, and hot spots should not exist in the column. Consequently, the catalyst life is expected to be enhanced and stable operations may be achieved.
- Operational costs may be reduced by up to 50% or more. Both labor and utilities for operation of the eliminated equipment items can be saved.

[0048] Overall, the processes described herein provide for a new processing scheme for alkylation of benzene, and provides an effective way to produce high purity alkylbenzene with much lower energy and utility consumption, and lower capital costs.

[0049] While the disclosure includes a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments may be devised which do not depart from the scope of the present disclosure. Accordingly, the scope should be limited only by the attached claims.

CLAIMS

What is claimed:

1. A process for the production of alkylbenzene, the process comprising:
feeding a C₁ to C₆ alcohol and benzene to a catalytic distillation reactor system comprising an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst;
concurrently in the catalytic distillation reactor system:
 reacting a portion of the alcohol with the benzene within the upper reaction zone to form a reaction mixture containing water, alkylbenzene, dialkyl ether, unreacted alcohol, unreacted benzene, and polyalkylate including dialkylbenzene;
 reacting a portion of the polyalkylate with benzene in the lower reaction zone to form additional alkylbenzene; and
 fractionally distilling the reaction mixture;
recovering an overheads fraction from the catalytic distillation reactor system comprising benzene, unreacted alcohol, water, and dialkyl ether;
recovering a bottoms fraction from the catalytic distillation reactor system comprising benzene, alkylbenzene, and polyalkylate.
2. The process of claim 1, wherein the alcohol is ethanol and the alkylbenzene is ethylbenzene.
3. The process of claim 1, wherein the alcohol is isopropanol and the alkylbenzene is cumene.
4. The process of claim 1, further comprising:
 operating the catalytic distillation reactor system such that the bottoms fraction comprises less than 0.03 wt.% benzene; and
 fractionating the bottoms fraction to recover an overheads fraction comprising alkylbenzene and benzene and a bottoms fraction comprising polyalkylate.
5. The process of claim 4, wherein the overheads fraction comprising ethylbenzene comprises at least 99.95 wt.% alkylbenzene.
6. A process for the production of ethylbenzene, the process comprising:

feeding ethanol and benzene to a catalytic distillation reactor system comprising an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst;

concurrently in the catalytic distillation reactor system:

reacting a portion of the ethanol with the benzene within the upper reaction zone to form a reaction mixture containing water, ethylbenzene, diethyl ether, unreacted ethanol, unreacted benzene, and polyalkylate including diethylbenzene;

reacting a portion of the polyalkylate with benzene in the lower reaction zone to form additional ethylbenzene; and

fractionally distilling the reaction mixture;

recovering an overheads fraction from the catalytic distillation reactor system comprising benzene, ethanol, water, and diethyl ether;

recovering a bottoms fraction from the catalytic distillation reactor system comprising benzene, ethylbenzene, and polyalkylate;

condensing and phase separating the overheads fraction to form a first liquid fraction comprising benzene and a second liquid fraction comprising the water, ethanol, and diethyl ether;

separating the bottoms fraction from the catalytic distillation reactor system in a first distillation column to recover an overheads fraction comprising benzene and a bottoms fraction comprising ethylbenzene and polyalkylate;

feeding at least a portion of the first liquid fraction to the catalytic distillation reactor system as a reflux;

separating the second liquid fraction in a second distillation column to recover an overheads fraction comprising ethanol and diethyl ether and a bottoms fraction comprising water;

feeding the ethanol feed and at least a portion of the overheads fraction from the second distillation column to the catalytic distillation reactor system intermediate the upper and lower reaction zones.

7. The process of claim 6, further comprising feeding a portion of the first liquid fraction to the catalytic distillation reactor system intermediate the upper and lower reaction zones.

8. The process of claim 6, further comprising separating the bottoms fraction from the first distillation column in a third distillation column to recover an overheads fraction comprising ethylbenzene and a bottoms fraction comprising polyalkylate.
9. The process of claim 6, further comprising separating the bottoms fraction from the first distillation column to recover an overheads fraction comprising ethylbenzene, a sidedraw fraction comprising diethylbenzene, and a bottoms fraction comprising polyalkylate.
10. The process of claim 9, further comprising feeding at least a portion of the sidedraw fraction to the catalytic distillation reactor system intermediate the upper and lower reaction zones.
11. The process of claim 10, wherein the sidedraw fraction further comprises triethylbenzene.
12. The process of claim 9, further comprising using the bottoms fraction comprising polyalkylate as a fuel blend stock.
13. The process of claim 6, wherein the condensing and phase separating the overhead fraction comprises indirect heat exchange of the overheads fraction from the catalytic distillation reactor system with at least one of:
 - at least a portion of the bottoms fraction comprising water;
 - at least a portion of the overhead fraction from the second distillation column;
 - water; and
 - steam.
14. The process of claim 6, wherein the catalyst in the upper reaction zone is the same as the catalyst in the lower reaction zone.
15. The process of claim 6, further comprising feeding the benzene feed, at least a portion of the first liquid fraction, and at least a portion of the overheads fraction from the first distillation column to the catalytic distillation reactor system as a reflux;
16. The process of claim 6, further comprising:
 - combining benzene and at least a portion of the overheads fraction from the second distillation column to form a mixture;
 - phase separating the mixture to recover a third liquid fraction comprising benzene, ethanol, and diethyl ether and a fourth liquid fraction comprising water, ethanol, and diethyl ether;
 - recycling the fourth liquid fraction to the second distillation column; and

feeding the third liquid fraction and a portion of the first liquid fraction to the catalytic distillation reactor system intermediate the upper and lower reaction zones.

17. The process of claim 16, comprising combining at least a portion of the overheads from the first distillation column, benzene, and at least a portion of the overheads fraction from the second distillation column to form the mixture.

18. A process for the production of cumene, the process comprising:

feeding isopropanol and benzene to a catalytic distillation reactor system comprising an upper reaction zone containing an alkylation catalyst and a lower reaction zone containing a transalkylation catalyst, which may be the same or different than the alkylation catalyst;

concurrently in the catalytic distillation reactor system:

reacting a portion of the isopropanol with the benzene within the upper reaction zone to form a reaction mixture containing water, cumene, diisopropyl ether, unreacted isopropanol, unreacted benzene, and polyalkylate including diisopropylbenzene;

reacting a portion of the polyalkylate with benzene in the lower reaction zone to form additional cumene; and

fractionally distilling the reaction mixture;

recovering an overheads fraction from the catalytic distillation reactor system comprising benzene, isopropanol, water, and diisopropyl ether;

recovering a bottoms fraction from the catalytic distillation reactor system comprising benzene, cumene, and polyalkylate;

condensing and phase separating the overheads fraction to form a first liquid fraction comprising benzene and a second liquid fraction comprising the water, isopropanol, and diisopropyl ether;

separating the bottoms fraction from the catalytic distillation reactor system in a first distillation column to recover an overheads fraction comprising benzene and a bottoms fraction comprising cumene and polyalkylate;

feeding at least a portion of the first liquid fraction to the catalytic distillation reactor system as a reflux;

separating the second liquid fraction in a second distillation column to recover an overheads fraction comprising isopropanol and diisopropyl ether and a bottoms fraction comprising water;

feeding the isopropanol feed and at least a portion of the overheads fraction from the second distillation column to the catalytic distillation reactor system intermediate the upper and lower reaction zones.

19. The process of claim 18, further comprising feeding a portion of the first liquid fraction to the catalytic distillation reactor system intermediate the upper and lower reaction zones.
20. The process of claim 18, further comprising separating the bottoms fraction from the first distillation column in a third distillation column to recover an overheads fraction comprising cumene and a bottoms fraction comprising polyalkylate.
21. The process of claim 18, further comprising separating the bottoms fraction from the first distillation column to recover an overheads fraction comprising cumene, a sidedraw fraction comprising diisopropylbenzene, and a bottoms fraction comprising polyalkylate.
22. The process of claim 21, further comprising feeding at least a portion of the sidedraw fraction to the catalytic distillation reactor system intermediate the upper and lower reaction zones.
23. The process of claim 22, wherein the sidedraw fraction further comprises tricumene.
24. The process of claim 21, further comprising using the bottoms fraction comprising polyalkylate as a fuel blend stock.
25. The process of claim 18, wherein the condensing and phase separating the overhead fraction comprises indirect heat exchange of the overheads fraction from the catalytic distillation reactor system with at least one of:
 - at least a portion of the bottoms fraction comprising water;
 - at least a portion of the overhead fraction from the second distillation column;
 - water; and
 - steam.
26. The process of claim 18, wherein the catalyst in the upper reaction zone is the same as the catalyst in the lower reaction zone.

27. The process of claim 18, further comprising feeding the benzene feed, at least a portion of the first liquid fraction, and at least a portion of the overheads fraction from the first distillation column to the catalytic distillation reactor system as a reflux;
28. The process of claim 18, further comprising:
- combining benzene and at least a portion of the overheads fraction from the second distillation column to form a mixture;
 - phase separating the mixture to recover a third liquid fraction comprising benzene, isopropanol, and diisopropyl ether and a fourth liquid fraction comprising water, isopropanol, and diisopropyl ether;
 - recycling the fourth liquid fraction to the second distillation column; and
 - feeding the third liquid fraction and a portion of the first liquid fraction to the catalytic distillation reactor system intermediate the upper and lower reaction zones.
29. The process of claim 28, comprising combining at least a portion of the overheads from the first distillation column, benzene, and at least a portion of the overheads fraction from the second distillation column to form the mixture.