

APPARATUS AND PROCESSES FOR PYROLYSIS OF PLASTIC FEEDS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Non-Provisional Patent Application
5 Serial No. 17/698,174 filed March 18, 2022, which claims benefit of and priority to U.S.
Provisional Patent Application Serial No. 63/217,051 filed June 30, 2021, and assigned
to the assignee hereof, the contents of which are hereby incorporated by reference in their
entireties.

FIELD

10 [0002] The present disclosure relates to apparatus and processes for pyrolysis of
feeds, such as plastic feeds.

BACKGROUND

[0003] Waste plastics are mostly diverted to landfills or are incinerated, with a smaller
fraction being diverted to recycling. However, over the years, with increased regulations
15 and levies on landfills, the percentage of the post-consumer waste being recycled or
incinerated for energy recovery is gradually increasing.

[0004] Attempts have been made to crack the plastic into useful products using
conventional cracking apparatus that are used for cracking of petroleum derived feeds
such as gas oils. For example, plastic feeds in powder form or pellets have been introduced
20 into fluidized catalytic cracking reactors, which, for plastic feeds, require high
temperatures.

[0005] In addition, the presence of chlorine in waste plastic (e.g., of
polyvinylchloride) promotes corrosion of reactor internals, requiring a separate
dechlorination process before the dechlorinated product can be introduced to a reactor
25 and other components of an apparatus. Such additional dechlorination steps (and reactors
for dechlorination) reduce throughput and yield of desired cracked products.

[0006] Further reducing throughput and yield are spent catalyst (formed in the
pyrolysis reactor during pyrolysis). Spent catalyst can be regenerated in a conventional
regenerator, but the amount of regeneration is insufficient particularly while using plastic
30 feeds containing chlorine and trace metals.

[0007] There is a need for apparatus and processes that provide high throughput of
feeds, such as plastic feeds, that can be converted by pyrolysis and catalytic upgrade to
form hydrocarbon products with high yields.

SUMMARY

[0008] The present disclosure relates to apparatus and processes for pyrolysis of feeds, such as plastic feeds.

[0009] In at least one embodiment, a process includes introducing a plastic melt including a plastic component into a reactor via a nozzle coupled with the reactor. The process includes introducing a catalyst into the reactor via a first conduit coupling the reactor with a riser, standpipe, or a regenerator. The process includes pyrolyzing the plastic component to form a pyrolysis product. The process includes removing the pyrolysis product from the reactor via a second conduit disposed at a top 1/2 height of the reactor. The process includes removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor, wherein the catalyst removed from the reactor comprises ash. The process includes introducing the catalyst from the third conduit to a separator to form a catalyst-rich phase and an ash-rich phase in the separator.

[0010] In at least one embodiment, a process includes removing a catalyst from a reactor, wherein the catalyst comprises ash. The process includes introducing the catalyst via a conduit to a separator to form a catalyst-rich phase and an ash-rich phase in the separator. The process includes introducing the catalyst-rich phase to a regenerator to form a regenerated catalyst. The conduit has an end disposed within the separator at a 1/4 to 3/4 height of the separator and the end comprises a plurality of outlets.

[0011] In at least one embodiment, a process includes introducing a plastic melt having a plastic component into a reactor via a nozzle coupled with the reactor. The process includes introducing a catalyst into the reactor via a first conduit coupling the reactor with a riser or regenerator. The process includes pyrolyzing the plastic component to form a pyrolysis product. The process includes removing the pyrolysis product from the reactor via a second conduit disposed at a top 1/2 height of the reactor. The process includes removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor.

[0012] These and other features and attributes of embodiments of the present disclosure and their advantageous applications and/or uses will be apparent from the detailed description which follows.

BRIEF DESCRIPTION OF THE FIGURES

[0013] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to aspects, some of which are illustrated in

the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical aspects of this present disclosure and are therefore not to be considered limiting of its scope, for the present disclosure may admit to other equally effective aspects.

5 [0014] FIG. 1 is an apparatus and process flow for pyrolysis of plastic feeds, according to an embodiment.

[0015] FIG. 2A is a nozzle, according to an embodiment.

[0016] FIG. 2B is a nozzle, according to an embodiment.

[0017] FIG. 3 is a separator, according to an embodiment.

10 [0018] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. The figures are not drawn to scale and may be simplified for clarity. It is contemplated that elements and features of one aspect may be beneficially incorporated in other aspects without further recitation.

15 **DETAILED DESCRIPTION**

[0019] The present disclosure relates to apparatus and processes for pyrolysis of feeds, such as plastic feeds.

[0020] In some embodiments, provided is a process including introducing a plastic melt including a plastic component into a reactor via one or more nozzles coupled with
20 the reactor. The process includes introducing a catalyst into the reactor using dilute-phase pneumatic transfer of regenerated catalyst coupled with the reactor via cyclone, standpipe, or vessel-dipleg system. The process includes pyrolyzing the plastic component to form a pyrolysis product. The process includes removing the pyrolysis product from the reactor via a second conduit disposed at a top 1/2 height of the reactor. The process
25 includes removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor, wherein the catalyst removed from the reactor comprises ash. The process includes introducing the catalyst from the third conduit to a separator to form a catalyst-rich phase and an ash-rich phase in the separator.

[0021] In some embodiments, provided is an apparatus including one or more nozzles
30 coupled with a reactor. The nozzle includes an inlet disposed substantially perpendicular to a horizontal conduit disposed in the nozzle. The apparatus includes a riser coupled with the reactor. The apparatus includes a first outlet conduit disposed at a top 1/2 height of the reactor. The first outlet conduit is coupled with a cyclone separator. The apparatus includes a second outlet conduit disposed at a bottom 1/2 height of the reactor. The

second outlet conduit is coupled with a second separator. The apparatus includes a regenerator coupled with the second separator and the riser.

[0022] Apparatus and processes of the present disclosure provide high throughput of pyrolysis products formed using pyrolysis of plastic. Processes can be performed as a single-stage process, providing higher yields than conventional processes for processing waste plastic. Apparatus and processes of the present disclosure provide elutriation of char, char ash, attrited catalyst, and co-injection material such that spent catalyst can be easily regenerated, providing improved throughput of the pyrolysis products in addition to higher purity of recycled catalyst to the reactor. In addition, use of catalyst having a narrow size distribution and larger average diameter than the co-injection material provides elutriation of co-injection material from the catalyst in the reactor. In addition, use of catalyst having a large average diameter, in addition to a reactor configured to provide bubble control, provides reduced plugging and wear of vessel conduits, valves, and other apparatus components, providing maintained integrity and a longer life cycle of apparatus of the present disclosure.

[0023] In addition, use of a separator of the present disclosure provides improved throughput of pyrolysis products because of improved separation of spent catalyst from components such as ash. Throughput is improved using the separator because, *inter alia*, the time intervals between apparatus shutdown can be lengthened because catalyst can remain viable (*e.g.*, the catalyst is regenerated). A separator of the present disclosure can also provide improved regeneration of spent catalyst (because ash is removed in the separator), which further improves throughput and yield of pyrolysis products.

Reactor Conditions

[0024] In some embodiments, provided is a process including introducing a plastic melt including a plastic component into a reactor via one or more nozzles coupled with the reactor. The process includes introducing a catalyst into the reactor by pneumatic transfer via a first conduit coupling the reactor with a riser. For example, the process may include introducing a catalyst into the reactor using dilute-phase pneumatic transfer of regenerated catalyst coupled with the reactor via cyclone-dipleg system. The process includes pyrolyzing the plastic component to form a pyrolysis product. The process includes removing the pyrolysis product from the reactor via a second conduit disposed

at a top 1/2 height of the reactor and removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor.

Apparatus and Process Flow

[0025] FIG. 1 is an apparatus **100** and process flow for pyrolysis of plastic feeds, according to an embodiment. Apparatus **100** includes a pyrolysis reactor **102**, a riser **102a**, a first separator **104**, a second separator **106**, and a regenerator **108**.

[0026] A plastic melt is introduced into pyrolysis reactor **102** via nozzle **110**. The plastic melt can include any suitable plastic material, such as plastic scrap, automotive plastic waste, thermoplastics, thermosets, or combination(s) thereof. The plastic melt can include one or more plastics such as polyethylene, polypropylene, polystyrene, polyethylene terephthalate, polyvinylchloride, or combination(s) thereof. The plastics can be obtained from recyclable plastics. For example, a bale comprising the plastics can be sorted into a plurality of portions, where at least one of the portions comprises one or more of the plastics. In some embodiments, the plastic melt is introduced into the reactor at a rate of about 60,000 lb/hr to about 100,000 lb/hr, such as about 75,000 lb/hr to about 85,000 lb/hr, alternatively about 30,000 lb/hr to about 50,000 lb/hr. The plastic melt can be provided to the nozzle **110** by a plastic melt source (not shown) that can be configured to provide heat to the plastic to form the plastic melt. In some embodiments, the plastic melt, upon being introduced to the reactor, has a solids (*e.g.*, char) content of about 20 wt% or less upon introduction into reactor **102**, such as about 15 wt% or less, such as about 10 wt% or less, such as about 5 wt% or less, such as about 1 wt% or less.

[0027] The plastic melt may further include a viscosity reducing agent. For example, a viscosity reducing agent can be a recycled portion of pyrolysis product, such as an organic compound (*e.g.*, aromatic or mono-olefin), such as an ethylene, a propylene, a butene, a benzene, a toluene, a xylene, or combination(s) thereof. The viscosity reducing agent may, additionally or alternatively, include a paraffinic organic compound such as a C₄-C₁₀₀ paraffin, such as a C₆-C₅₀ paraffin, such as a C₁₀-C₃₀ paraffin. The viscosity reducing agent can be introduced to the plastic melt in the plastic melt source (not shown) or nozzle **110**. In some embodiments, a weight ratio of plastic to viscosity reducing agent (upon introduction to the reactor) is about 0.5:1 to about 1.5:1, such as about 1:1. In some embodiments where the plastic melt includes a viscosity reducing agent, the plastic melt is introduced into the reactor at a rate of about 60,000 lb/hr to about 200,000 lb/hr, such

as about 120,000 lb/hr to about 200,000 lb/hr, such as about 148,000 lb/hr to about 172,000 lb/hr.

[0028] A catalyst can be introduced into the pyrolysis reactor **102** via a first conduit **112**. Conduit **112** couples reactor **102** to riser **102a**. Conduit **112** can be disposed at a top 1/2 height of the reactor (as shown in FIG. 1) or alternatively can be a dipleg return coupled with riser **102a** at a first end and the reactor **102** at a second end such that the second end of the dipleg return (conduit **112**) is disposed at the bottom 1/2 height of the reactor.

[0029] The plastic melt and the catalyst in reactor **102** pyrolyze the plastic(s) to form a pyrolysis product. In some embodiments, the catalyst is introduced into reactor **102** via the first conduit **112** at a catalyst flow rate of about 5.5 tons per minute to about 13.8 tons per minute, such as about 7.5 tons per minute to about 12.4 tons per minute, alternatively about 2.5 tons per minute to about 8.8 tons per minute. In some embodiments, the catalyst disposed in the riser **102a** has a minimum gas fluidization velocity of about 0.4 ft/sec to about 0.6 ft/sec. In some embodiments, a weight ratio of catalyst to feed (*e.g.*, plastic melt with or without viscosity reducing agent) in reactor **102** is about 15:1 to about 5:1, such as about 11:1 to about 7:1, such as about 9:1.

[0030] The pyrolysis product is removed from reactor **102** via a second conduit **114** disposed at a top 1/2 height of the reactor. The catalyst is removed from reactor **102** via a third conduit **116** disposed at a bottom 1/2 height of the reactor. For example, the catalyst can be removed from the reactor via third conduit **116**, where third conduit **116** is disposed at a bottom surface of the reactor **102**.

[0031] In some embodiments, reactor **102** is a bubbling bed reactor. Alternatively, a fluidized bed reactor, slurry reactor, rotating kiln reactor, or packed bed reactor may be used. The plastic melt (*e.g.*, without viscosity reducing agent) can have a temperature of about 900 °F to about 1,100 °F, such as about 1,000 °F to about 1,050 °F, alternatively about 900 °F to about 1,020 °F, during introducing the plastic melt into the reactor. Alternatively, the plastic melt (*e.g.*, with viscosity reducing agent) can have a temperature of about 300 °F to about 700 °F, such as about 350 °F to about 665 °F, during introducing the plastic melt into the reactor.

[0032] In some embodiments, a reactor temperature during pyrolysis of the plastic melt is about 900 °F to about 1,100 °F, such as about 1,000 °F to about 1,050 °F, alternatively about 900 °F to about 1,020 °F. For example, pyrolyzing the plastic may be performed at a reactor temperature of about 900 °F to about 1,100 °F, such as about 1,000

°F to about 1,050 °F, and/or a reactor pressure of about 20 psig to about 40 psig, such as about 27 psig to about 33 psig.

[0033] Pyrolysis of the present disclosure can provide the pyrolysis product such that the pyrolysis product includes valuable monomers of light gas olefins and aromatics, such as benzene, toluene, xylenes, or combination(s) thereof. The process yields are tunable to the desired yields of olefins and aromatics by using a combination of the catalyst, reactor setup, and process operating conditions. The pyrolysis product can include an organic compound, such as a C₂-C₁₂ hydrocarbon. In some embodiments, the pyrolysis product includes an organic compound selected from the group consisting of ethylene, propylene, and combination(s) thereof. In some embodiments, the pyrolysis product includes an organic compound selected from the group consisting of an ethylene, a propylene, a butene, a benzene, a toluene, a xylene, and combination(s) thereof.

[0034] In some embodiments, in addition to the catalyst, a co-injection particle is introduced into reactor **102**. For example, a co-injection particle can be introduced into reactor **102** via nozzle **110** at a rate of about 1,000 lb/hr to about 3,000 lb/hr. In some embodiments, a co-injection particle is a particle configured to trap halogens (*e.g.*, fluorine, chlorine, bromine or iodine present in polymers or contaminants of the plastic melt). During the pyrolysis process, such halogens may appear as unwanted contaminants in desired pyrolysis products, or they may be deposited on or react with pyrolysis catalyst components, thereby reducing desirable catalyst properties such as activity and selectivity to desired pyrolysis products. Further, such halogens may be deposited on or react with mechanical components of the pyrolysis system, leading to damage, reduced efficiency or mechanical failure. Further, such halogens may appear as noxious gases or in liquid effluents from outlets of the pyrolysis system. Co-injection particles configured to trap or sequester halogens may include but are not limited to oxides, carbonates, calcium oxide, calcium carbonate, limestone, metal oxides, mixed metal oxides, clays, sands, earths, zeolites, or any other material or combination of materials able to combine with or sequester one or more halogens, in reversible or irreversible manners, thereby reducing or eliminating halogens from desired pyrolysis products, or thereby reducing or eliminating their deleterious deposition on or reaction with pyrolysis catalyst components, or thereby reducing or eliminating their deleterious deposition on or reaction with mechanical components of the pyrolysis system, or thereby reducing or eliminating their appearance as noxious gases or in liquid effluents from outlets of the pyrolysis system. For example, the co-injection particle can be oxides,

carbonates, calcium oxide, calcium carbonate, limestone, metal oxides, mixed metal oxides, clays, sands, earths, zeolites, or any other material or combination(s) of materials capable of combining with and sequestering halogens.

[0035] In some embodiments, a co-injection particle comprises a material or combination of materials configured to trap or sequester metals and semi-metals that may be present in the plastic melt. A variety of metals and semi-metals may be present in plastic wastes, particularly post-consumer plastic wastes. These metals and semi-metals may include but are not limited to alkali metals, alkaline earth metals, transition metals, rare earths, iron, silver, copper, zinc, gray tin, lead, phosphorus and aluminum, and may be present as free elements or may be present as inorganic or organic or organometallic molecules, compounds, aggregations, mixtures or other combination(s). During the pyrolysis process, such metals and semi-metals may appear as unwanted contaminants in desired pyrolysis products, or they may be deposited on or react with pyrolysis catalyst components, thereby reducing desirable catalyst properties such as activity and selectivity to desired pyrolysis products. Further, such metals and semi-metals may be deposited on or react with mechanical components of the pyrolysis system, leading to damage, reduced efficiency or mechanical failure. Co-injection particles configured to trap or sequester metals and semi-metals may include but are not limited to oxides, carbonates, calcium oxide, calcium carbonate, limestone, metal oxides, mixed metal oxides, clays, sands, earths, zeolites, or any other material or combination of materials able to combine with or sequester one or more metals or semi-metals, in reversible or irreversible manners, thereby reducing or eliminating them from desired pyrolysis products, or thereby reducing or eliminating their deleterious deposition on or reaction with pyrolysis catalyst components, or thereby reducing or eliminating their deleterious deposition on or reaction with mechanical components of the pyrolysis system.

[0036] "4A zeolite" (also referred to as LTA zeolite) means a zeolite having pore openings of about 4 angstroms; and the term "5A zeolite" means a zeolite having pore openings of about 5 angstroms.

[0037] 4A zeolites ($\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{SiO}_2 \cdot 9/2 \text{H}_2\text{O}$) have a continuous three-dimensional network of channels approximately 4 angstrom in diameter, in addition to larger "cages" approximately 7 Å in diameter. 4A zeolites can have one or more of the following properties: (1) an average particle size of about 3 microns; and/or (2) a silicon:aluminum ratio of about 1.

[0038] The pore structure of the 5A zeolites ($3/4 \text{ CaO} \cdot 1/4 \text{ Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2 \cdot 9/2 \text{ H}_2\text{O}$) is a three-dimensional network of intersecting channels. Entry to the channels is controlled by the eight oxygen atoms from which they are formed (approx. 3-5 Å diameter). Where the channels intersect, larger pores or cages with diameters of 11.4 Å are formed. 5A zeolites can have a bulk density of about 0.7 g/cm³ to about 0.75 g/cm³,
5 such as about 0.72 g/cm³.

[0039] If calcium oxide is used, the calcium oxide can react with chlorine content of the polymer melt to form calcium chloride and gas product(s) such as carbon dioxide. In some embodiments, a weight ratio of catalyst to co-injection particle in reactor 102 is
10 about 10:1 to about 30:1, such as about 15:1 to about 25:1, such as about 20:1.

[0040] The co-injection particle, or product thereof, after sequestration of one or more halogens, or after sequestration of one or more metals or semi-metals, or after sequestration of combinations of one or more halogens, metals or semi-metals, can be removed from the reactor via second conduit 114 and introduced into first separator 104
15 along with the pyrolysis product.

[0041] In some embodiments, the co-injection particle has a smaller average diameter than the average diameter of the pyrolysis catalyst. In such embodiments, in combination with other parameters of the pyrolysis reactor 102, the co-injection particle, or reaction product thereof, (and/or char and attrited catalyst) is able to be removed from reactor 102
20 to first separator 104 (via a conduit disposed at a top 1/2 height of the reactor), whereas the larger catalyst particles are removed from reactor 102 via third conduit 116 disposed at a bottom 1/2 height of the reactor. In some embodiments, a co-injection particle has an average diameter of less than 400 microns, such as less than 200 microns, such as about 50 microns to about 400 microns, such as about 75 microns to about 200 microns,
25 and/or the catalyst has an average diameter of about 500 microns to about 600 microns and/or a narrow particle size distribution. For example, the catalyst can have a D1% value of about 400 microns and a D99% value of about 700 microns.

[0042] First separator 104 can be a cyclone separator that is configured to separate the co-injection particle, or product thereof, from the pyrolysis product. The co-injection
30 particle, or product thereof, is removed from first separator 104 via fifth conduit 120 for storage or further processing (e.g., disposal or regeneration). The pyrolysis product is removed from first separator 104 via conduit 118 for storage or further processing (e.g., additional cyclonic separation and/or distillation of products). For example, a second stage of cyclone(s) for secondary removal can be used to increase separation

efficiency. Subsequent devices for separation of solids and gases from pyrolysis product can include cyclones, hot gas filters, vortex separators, electrostatic separation, or combination(s) thereof, which can be further added to achieve desired solid removal efficiency.

5 [0043] The catalyst (*e.g.*, spent catalyst) from reactor **102** is introduced into separator **106**. In some embodiments, separator **106** is a solid-solid separator. A co-injection particle, or product thereof, from the pyrolysis product can also be removed from separator **106** via sixth conduit **122**.

[0044] Spent catalyst and ash enter a mid-portion of separator **106**. The spent catalyst
10 and ash may further include any residual co-injection particle not separated from the catalyst/ash in the reactor **102**. FIG. 3 is a separator **106** of the present disclosure. As shown in FIG. 3, the second end of third conduit **116** is disposed at an angle of about 60° or greater to promote gravimetric flow of the mixture of spent catalyst and ash into separator **106** via third conduit **116**. Although the angle shown is about 60°, any suitable
15 angle can be used, such as about 10° to about 90° (vertical inlet), such as about 30° to about 75°, such as about 45° to about 60°. Additionally or alternatively, gas can be introduced into third conduit **116** to promote the flow of the mixture of spent catalyst and ash in third conduit **116** and into separator **106**.

[0045] In some embodiments, the mixture of spent catalyst and ash entering reactor
20 **106** includes about 90 wt% or greater spent catalyst and about 10 wt% or less ash, such as about 0.5 wt% to about 4 wt% ash and about 96 wt% to about 99.9 wt% spent catalyst. Spent catalyst and ash is introduced into separator **106** at a temperature of about 800 °F to about 1,200 °F, such as about 950 °F to about 1,050 °F. In some embodiments, spent catalyst and ash are introduced to separator **106** at a rate of about 1 million lbs/hr to about
25 2 million lbs/hr, such as about 1.3 million lbs/hr to about 1.7 million lbs/hr, such as about 1.4 million lbs/hr to about 1.7 million lbs/hr.

[0046] Third conduit **116** has a first end coupled with reactor **102** (of FIG. 1) and a second end coupled with separator **106**. As shown in FIG. 3, the second end of third conduit **116** has a plurality of outlets **310a**, **310b**, and **310c** for providing the mixture of
30 spent catalyst and ash into separator **106**. Although three outlets **310a-310c** are shown in FIG. 3, the second end of third conduit **116** can have any suitable number of outlets, such as a single outlet or about 2 to about 20 outlets, such as about 3 to about 10 outlets, such as about 4 to about 6 outlets. Outlets can be fully or partially open to the separator. A plurality of outlets disposed at the second end of third conduit **116** promotes uniform

distribution of the mixture of spent catalyst and ash into separator **106** which, in combination with one or more other features of separator **106**, promotes separation of the spent catalyst from the ash. Further, during use, the second end of third conduit **116** is disposed in ash-rich phase **304** (*e.g.*, the second end is disposed at a mid-portion of separator **106** such as disposed at a 1/4 to 3/4 height of the separator) which promotes separation of spent catalyst from the ash of the mixture being introduced into separator **106** via outlets **310a-c** by allowing separation of spent catalyst from the ash followed by settling of the spent catalyst. Once introduced to separator **106**, ash separates from the spent catalyst and the ash settles to form the ash-rich phase **304**. Likewise, spent catalyst separates from the ash and the spent catalyst settles from the mid-portion of separator **106** toward the bottom portion of separator **106** to form the catalyst-rich phase **302**. The “catalyst-rich phase” is rich in spent catalyst and can optionally include an amount of catalyst that is not spent.

[0047] Gas is introduced into separator **106** via seventh conduit **306** to fluidize the mixture of spent catalyst and ash. Gas can be provided at a rate of about 0.1 ft/s to about 1.5 ft/s, such as about 0.3 ft/s to about 0.7 ft/s, such as about 0.5 ft/s. The gas can have a temperature of about 150 °F to about 1050 °F. The gas can have a lower temperature than the spent catalyst and ash entering separator **106** via third conduit **116** such that the gas can promote cooling of the spent catalyst and ash. In some embodiments, the gas introduced can replace the presence of the trapped reactor gases prior to the introduction into the regenerator combustion system. The rate of gas introduced into separator **106** via seventh conduit **306** can be such that a fine balance is reached between the gas’ ability to promote separation of the spent catalyst from the ash and allow the spent catalyst’s ability to separate/settle gravimetrically from the ash. Gas in the separator **106** can exit separator **106** via sixth conduit **122** and/or dipleg conduit **308**. Ash of ash-rich phase **304** is removed from separator **106** via dipleg outlet **308**.

[0048] As shown in FIG. 3, the catalyst-rich phase **302** is shown as a bottom phase below the ash-rich phase **304** because, in the embodiments of FIG. 3, the spent catalyst has a higher density and/or a larger particle size than the ash of the ash-rich phase **304**. In alternative embodiments, catalyst-rich phase **302** can have a lower density and/or smaller particle size than ash-rich phase **304** and catalyst-rich phase **302** can be above the ash-rich phase **304** in separator **106**. In such embodiments, the catalyst-rich phase **302** would be removed from separator **106** via a conduit (not shown) disposed at a mid-portion of separator **106**, and the spent catalyst removed by the conduit (not shown) would

provide the spent catalyst to the regenerator **108** of FIG. 1. Further in such embodiments, the ash of the ash-rich phase **302** would be disposed toward a bottom portion of separator **106**, and the ash would be removed from separator **106** by a conduit (not shown) disposed at a bottom portion of separator **106** for disposal or further processing.

5 **[0049]** A separation carried out in separator **106** to form the multiple phases can be performed at any suitable pressure and temperature. In some embodiments, a pressure in separator **106** is about 20 psig to about 50 psig, such as about 25 psig to about 40 psig, such as about 30 psig to about 35 psig. In some embodiments, a temperature in separator **106** is about 700 °F to about 1,200 °F, such as about 850 °F to about 1,050 °F, such as
10 about 950 °F to about 1,000 °F.

[0050] In some embodiments, the spent catalyst obtained from separator **106** is about 90 wt% or greater, such as about 96 wt% to about 99.9 wt% spent catalyst, relative to the mixture of spent catalyst and ash introduced into separator **106**. Likewise, the ash obtained from separator **106** is about 10 wt% or less, such as about 0.5 wt% to about 4
15 wt% ash, relative to the mixture of spent catalyst and ash introduced into separator **106**.

[0051] In embodiments where sand is also used in reactor **102** in addition to catalyst, the sand can be separated in separator **106** (*e.g.*, as part of the catalyst-rich phase or as a third phase in addition to the catalyst-rich phase and ash-rich phase). For example, the sand can be disposed in a sand-rich phase that is disposed above or below the catalyst-rich phase **302**, and the sand-rich phase can be disposed below the ash-rich phase **304**. In
20 such embodiments, the sand-rich phase will be removed from separator **106** via a conduit (not shown) that is disposed below the ash-rich phase **304** and the sand of the sand-rich phase would be removed from separator **106** via the conduit (not shown) that is disposed below the conduit that removed the ash from separator **106**.

25 **[0052]** Additionally or alternatively, in embodiments where trace metals (such as chromium) are separated from the spent catalyst in separator **106**. Because trace metals can be denser than a spent catalyst, the trace metals can be separated from spent catalyst and settle as in separator **106** as a metal-rich phase that is disposed below the catalyst-rich phase **302**. In such embodiments, the metal-rich phase will be removed from
30 separator **106** via a conduit (not shown) that is disposed below the catalyst-rich phase **302** and the spent-catalyst of the catalyst-rich phase **302** would be removed from separator **106** via a conduit (not shown) that is disposed above the conduit that removed the trace metal from separator **106**.

[0053] In some embodiments, the conduit used to remove the ash-rich phase from separator can be disposed towards another separator or divided walls acting in series or in stages. Each series or stage geometry can be configured to be separate vessels or discrete chambers integrated into one vessel. Gas can be provided at a rate of about 0.05 ft/s to about 1.5 ft/s, such as about 0.1 ft/s to about 0.3 ft/s, such as about 0.1 ft/s where separation of a third or fourth phase within the ash-rich phase can be achieved to increase separation efficiency from the catalyst-rich phase.

[0054] From separator **106**, the catalyst (*e.g.*, spent catalyst) is introduced into regenerator **108** via conduit **140** that is configured to form a regenerated catalyst. An oxygen-carrying gas, such as air, may be introduced into the regenerator **108** to regenerate the spent catalyst and combust material (*e.g.*, carbonaceous material disposed on the catalyst such as ash). In some embodiments, air is introduced into the regenerator **108** at a rate of about 107,000 lb/hr to about 165,000 lb/hr, such as about 133,000 lb/hr to about 151,000 lb/hr, such as about 145,000 lb/hr.

[0055] The regenerated catalyst formed in regenerator **108** is then introduced into riser **102a**.

[0056] In some embodiments, the plastic melt is not introduced to the riser **102a**. A gas, such as pygas, product gases, reactant gases, recycle gases, or combination(s) thereof, is introduced to the riser **102a** via inlet **132**. For example, gas is introduced to the riser **102a** at a rate of about 18,000 lb/hr to about 23,000 lb/hr, such as about 21,000 lb/hr to about 22,000 lb/hr.

[0057] In some embodiments, gas is introduced into reactor **102** via inlet **130**. For example, gas can be introduced into reactor **102** via the nozzle at a rate of about 3,000 lb/hr to about 12,000 lb/hr, such as about 7,750 lb/hr to about 10,250 lb/hr. A nozzle can have an outlet having a diameter of about 6 mm to about 20 mm, such as about 13 mm.

[0058] The gas introduced to the riser **102a** and/or reactor **102** can be refined, product recycled fluid (*e.g.*, gas or liquid). The gas provides a fluidization medium in reactor **102** and also provides improved conversion/yield of reactor feed into pyrolysis product. For example, in embodiments where the gas is a recycled fluid, the recycled fluid can contain olefin material that provides conversion towards a pyrolysis product such as aromatics, increasing target product yield.

[0059] In some embodiments, gas (and/or co-injection material and/or recycle oil) is introduced into the reactor indirectly via an inlet of nozzle **110** and nozzle **110** has an outlet diameter that is smaller than a nozzle interior diameter (as shown in FIG. 2B). For

example, a nozzle can have a largest interior diameter of about 10 mm to about 20 mm, such as about 15 mm, and the nozzle can have an outlet having a diameter of about 4 mm to about 12 mm, such as about 8 mm. Gas (in combination with recycle oil) injected into the inlet of the nozzle helps initial shear of the plastic melt into fine droplets. The narrow outlet shears the material again into fine droplets, *e.g.*, 70-80 microns, and disperses the droplets. The fine droplets allow heating of the material quickly for pyrolysis (with less undesired byproduct formation due to reduced residence time needed in the reactor).

[0060] During use, catalyst particles in reactor **102** can be in an emulsion phase. Because gas is introduced through riser **102a**, into reactor **102**, and chemical reaction effluent, bubbles can form within reactor **102**. Reactor **102** can be configured to break bubbles that form in the reactor **102**. By breaking bubbles in reactor **102**, mass transfer of plastic melt to catalyst is promoted. For example, molecules of pyrolyzed plastic getting into pores of catalyst is promoted, which promotes better conversion of plastic to pyrolysis product(s). In addition, formation of large bubbles promotes mechanical vibrations within the reactor, so breaking of the bubbles can reduce or eliminate the occurrence of mechanical vibrations promoted by large bubbles.

[0061] In some embodiments, reactor **102** has a plurality of plates, mesh, or structure grid sheds (not shown) disposed within the reactor. For example, the plurality of plates, mesh, or structured grids can have an arrangement in a first row and a second row of plates, mesh, or structured grids, where the first row is horizontally offset from the second row. In some embodiments, one or more of the mesh or grid sheds have an angular apex cover in a vertical direction and have one or more openings along its cover.

Catalysts

[0062] The catalyst(s) used for pyrolysis of the plastic melt can be any suitable pyrolysis catalyst. In some embodiments, a catalyst is a composite body with multiple components. These components may include one or more materials that are catalytically active in the conversion of plastics in the reactor feed to desired pyrolysis products. These components may, for example, include but are not limited to zeolites, clays, acid impregnated clays, aluminas, silicas, silica-aluminas, spent FCC catalysts, equilibrium FCC catalysts, metal oxides, mixed metal oxides, or combination(s) thereof. The catalyst components may also include one or more materials to bind the catalyst components together to improve their physical strength. Such binder materials may for example

include, but are not limited to various aluminas, silicas, magnesias, clays and other earths and minerals. The catalyst components may also include one or more materials to modify other aspects of the composite catalyst bodies, for example density, porosity and pore size distribution. Such modifying materials may include, but are not limited to various
5 aluminum oxides, aluminum hydroxides, aluminum oxyhydroxides, clays, earths, fillers, or combination(s) thereof. Further, such modifying materials may function as hardeners, densifiers, burn out materials to enhance porosity, stabilizers, diluents, activity promoters, activity stabilizers, or combination(s) thereof. Further such modifying materials may include one or more components to sequester feed contaminants such as metals, semi-
10 metals or halogens. Further, such modifying materials may include one or more components to reduce emissions of sulfur oxides, nitrogen oxides, or acid gases from the pyrolysis system. Further, such modifying materials may include one or more components to control and regulate the combustion of carbon and emissions of carbon oxides from the pyrolysis system regenerator. In some embodiments, an additive material is a matrix
15 formed from an active material, such as an active alumina material (amorphous or crystalline), a binder material (such as alumina or silica), an inert filler (such as kaolin), or combination(s) thereof. For example, the catalyst can include a zeolite material disposed in the matrix.

[0063] In some embodiments, the various catalyst components are in bodies of one
20 homogeneous composition. In other embodiments, the various components are distributed between two or more bodies that can be physically mixed to achieve the overall desired amounts of the various individual components.

[0064] In some embodiments, the catalyst is a Group VIII metal or compound thereof, a Group VIB metal or a metal compound thereof, a Group VIIB metal or a metal
25 compound thereof, or a Group IIB metal or a metal compound thereof, or combination(s) thereof. For example, a Group VIB metal or compound thereof can include molybdenum and/or tungsten. A Group VIII metal or a compound thereof may include nickel and/or cobalt. A Group VIIB metal or a compound thereof may include manganese and/or rhenium. A Group IIB metal or a compound thereof may include zinc and/or cadmium.
30 In some embodiments, a catalyst is a sulfided catalyst. In some embodiments, a catalyst is a cobalt-molybdenum catalyst, a nickel-molybdenum catalyst, a tungsten-molybdenum catalyst, sulfide(s) thereof, or combination(s) thereof. In some embodiments, the catalyst is a platinum-molybdenum catalyst, a tin-platinum catalyst, a platinum gallium catalyst, a platinum-chromium catalyst, a platinum-rhenium, or combination(s) thereof. In some

embodiments, a catalyst includes cobalt and molybdenum, nickel and molybdenum, iron and molybdenum, palladium and molybdenum, platinum and molybdenum, or nickel and platinum. A Group IIIB metal or a compound thereof may include lanthanum and/or cerium.

- 5 [0065] In some embodiments, catalytically active components may include one or more zeolites, which may include but are not limited to X-types, Y-types, mordenites, may be an X-type zeolite, a Y-type zeolite, USY-type zeolite, mordenite, faujasite, nano-crystalline zeolite, an MCM mesoporous material, SBA-15, a silico-alumino phosphate, a gallophosphate, a titanophosphate. In some embodiments, the catalyst may include one
10 or more zeolites (or metal loaded zeolites). In some embodiments, a zeolite is ZSM-5, ZSM-11, aluminosilicate zeolite, ferrierite, heulandite, zeolite A, erionite, chabazite, or combination(s) thereof.

- [0066] In some embodiments, a catalytically active component is a zeolite, such as a medium-pore zeolite, such as a ZSM-5 zeolite. ZSM-5 zeolite is a molecular sieve that
15 is a porous material having intersecting two-dimensional pore structure with 10-membered oxygen-containing rings. Zeolite materials with such 10-membered oxygen ring pore structure are often classified as medium-pore zeolites. Such medium-pore zeolites typically have pore diameters of 5.0 Angstroms (Å) to 7.0 Å. ZSM-5 zeolite is a medium pore-size zeolite having a pore diameter of about 5.1 Å to about 5.6 Å.

- 20 [0067] Other properties of ZSM-5 zeolite can include one or more of the following: (1) a $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio of about 20 to about 600, such as about 30; (2) a Brunauer–Emmett–Teller (BET) surface area (m^2/g) of about 320 or greater, such as about 340 or greater, such as about 320 to about 380, such as about 340; and/or (3) in the hydrogen or ammonium ion exchange form.

- 25 [0068] Catalysts of the present disclosure can have a particle size small enough (1) to allow homogeneous reactor and regenerator fluidization without extreme velocities required, (2) to provide good contacting of catalyst to feed (*e.g.*, plastic melt, recycled pygas, etc.) and reduce/minimize external diffusion barriers, (3) to allow for smooth regeneration without hot spots that might arise if particles are too large, and/or (4) to
30 allow for smooth pneumatic transport without a need for high gas velocities. Catalysts of the present disclosure can have a large enough particle size and density (1) to allow high ratio of catalyst to feed during pyrolysis, (2) to allow higher space velocities (throughput) while minimizing entrainment, (3) to allow for good catalyst separation and discharge from reactor bottom and regenerator bottom, and/or (4) allow efficient separation from

lighter, smaller ash or separable phase (non-catalyst solids such as char, co-injected materials) if a separator is used. In some embodiments, the catalyst has an average diameter of about 450 microns to about 650 microns, such as about 500 microns to about 600 microns, such as about 540 microns to about 560 microns.

5 [0069] In some embodiments, the catalyst can have a narrow diameter distribution. For example, the catalyst may have a diameter distribution of about +/- 200 microns of the average diameter of the catalyst, such as about +/- 150 microns, such as about +/- 75 microns. In some embodiments, the catalyst has a D1% value of about 380 microns to about 420 microns, such as about 400 microns. D1% is the diameter of the catalyst such
10 that 99 wt% of the catalyst has a diameter greater than the D1% value. In some embodiments, the catalyst has D99% value of about 680 microns to about 720 microns, such as about 700 microns. D99% is the diameter of the catalyst such that 99 wt% of the catalyst has a diameter less than the D99% value. A narrow size (*e.g.*, diameter) distribution of a catalyst can (1) reduce or minimize dense phase segregation in the reactor
15 and the regenerator, (2) reduce or minimize preferential transport and dilute phase transport at high feed or regenerator air rates, and/or (3) reduce or minimize plugging at vessel discharge ports, slide valves, Y-joints, etc.

[0070] In some embodiments, the catalyst has an average particle density of about 300 g/l to about 1,200 g/l, such as about 500 g/l to about 1,000 g/l, such as about 600 g/l
20 to about 800 g/l.

[0071] In some embodiments, the catalyst has a sphericity of about 0.9 or greater, such as about 0.95 or greater, such as about 0.99 or greater.

[0072] In some embodiments, the catalyst has an active catalyst (*e.g.*, zeolite) loading amount of about 50 wt% or greater, such as about 60 wt% or greater, such as about 75
25 wt% or greater, such as about 85 wt% or greater, where a remainder balance of the catalyst comprises additive material. For example, additive material can include any suitable binder material.

[0073] A catalyst of the present disclosure can have an attrition resistance referred to as an attrition resistance index of less than 10 when measured in a jet cup apparatus at an
30 air jet velocity of 200 ft/sec.

[0074] A catalyst of the present disclosure can have a crush strength greater than 1 Newton as measured in a single bead anvil test apparatus, such as greater than 5 Newtons.

[0075] In some embodiments, a catalyst is in the form of granules, pellets, extrudates, cut extrudates, ligated extrudates, beads, tablets, spheres, or combination(s) thereof.

[0076] Catalysts of the present disclosure may be obtained by any suitable process (such as spray drying) and/or may be obtained from a commercial source. For example, a catalyst can be formed by spray drying, prilling, oil dropping, water dropping, granulating, fluid bed agglomeration, spray coating tableting, extruding, or any combination(s) thereof. Catalysts can be cut, crushed, milled, or screened to provide any suitable size (*e.g.*, diameter) distribution. Catalysts can be further prepared by polishing, densifying, or spheronizing in rotating pans, rotating drums, and the like.

[0077] More than one type of catalyst may be introduced to the reactor **102**. For example, a first catalyst is introduced to the reactor **102** by a conduit and a second catalyst is introduced to the reactor **102** by a different conduit. The first catalyst and the second catalyst can be introduced into the reactor **102** at the same or different flow rates to control relative amounts of catalyst in reactor **102** at any given time. A remainder balance of the first catalyst and/or the second catalyst can include additive material, such as binder material.

[0078] Additionally or alternatively, a first catalyst and a second catalyst are introduced to reactor **102** via a single conduit (as a mixture of catalysts). For example, the mixture of catalysts can be a single-body catalyst including the two catalysts. A remainder balance of the single-body catalyst can include additive material, such as binder material.

[0079] In some embodiments, sand of a density of about 1450 g/l to about 1680 g/l can be mixed with a catalyst. Examples of sand include quartz sand, silica sand, sand containing metal or metal oxide, or combination(s) thereof. The use of sand may inhibit fouling of the catalyst by contaminants produced during the pyrolysis. Sand can also provide control of thermal and catalytic activities of pyrolysis occurring in the reactor. Sand may be used at an amount of up to about 99 wt% based on the total amount of sand + catalyst.

ADDITIONAL ASPECTS

[0080] The present disclosure provides, among others, the following aspects, each of which may be considered as optionally including any alternate aspects.

Clause 1. A process, comprising:

introducing a plastic melt comprising a plastic component into a reactor via a nozzle coupled with the reactor;

introducing a catalyst into the reactor via a first conduit coupling the reactor with a riser or a regenerator;

5 pyrolyzing the plastic component to form a pyrolysis product;

removing the pyrolysis product from the reactor via a second conduit disposed at a top 1/2 height of the reactor;

removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor, wherein the catalyst removed from the reactor comprises ash; and

10 introducing the catalyst from the third conduit to a separator to form a catalyst-rich phase and an ash-rich phase in the separator.

Clause 2. The process of Clause 1, wherein the third conduit is disposed at an angle of about 30° to about 90° relative to a substantially vertical side of the separator.

15 Clause 3. The process of Clauses 1 or 2, further comprising introducing a gas to the third conduit.

Clause 4. The process of any of Clauses 1 to 3, wherein the catalyst introduced to the separator has a temperature of about 950 °F to about 1,050 °F when introduced to the separator and is introduced to the separator at a rate of about 1.3 million lbs/hr to about 1.7 million lbs/hr.

20 Clause 5. The process of any of Clauses 1 to 4, wherein the third conduit has an end disposed within the separator and the end comprises a plurality of outlets.

Clause 6. The process of any of Clauses 1 to 5, wherein the end of the third conduit is disposed at a 1/4 to 3/4 height of the separator.

25 Clause 7. The process of any of Clauses 1 to 6, further comprising introducing a gas into the separator via a fourth conduit at a rate of about 0.3 ft/s to about 0.7 ft/s, wherein the gas has a temperature of about 150 °F to about 1050 °F.

- Clause 8. The process of any of Clauses 1 to 7, wherein forming the catalyst-rich phase and the ash-rich phase in the separator is performed at a pressure of about 25 psig to about 40 psig and a temperature of about 850 °F to about 1,050 °F.
- Clause 9. The process of any of Clauses 1 to 8, further comprising introducing the catalyst-rich phase to the regenerator.
- Clause 10. The process of any of Clauses 1 to 9, wherein the catalyst introduced into the reactor comprises a zeolite and sand and the catalyst introduced from the third conduit to the separator comprises the zeolite, the sand, and the ash.
- Clause 11. The process of any of Clauses 1 to 10, wherein introducing the catalyst from the third conduit to the separator further forms a sand-rich phase in the separator, the process further comprising removing the sand-rich phase from the separator via a fourth conduit.
- Clause 12. The process of any of Clauses 1 to 11, further comprising sorting a bale comprising the plastic component into a plurality of portions, wherein at least one of the portions comprises the plastic component.
- Clause 13. The process of any of Clauses 1 to 12, wherein the reactor is a bubbling bed reactor and the plastic melt has a temperature of about 900 °F to about 1,100 °F during introducing the plastic melt into the reactor.
- Clause 14. The process of any of Clauses 1 to 14, wherein the plastic component is selected from the group consisting of polyethylene, polypropylene, polystyrene, polyethylene terephthalate, polyvinylchloride, and combination(s) thereof.
- Clause 15. The process of any of Clauses 1 to 14, wherein the pyrolysis product comprises an organic compound selected from the group consisting of an ethylene, a propylene, a butene, a benzene, a toluene, a xylene, and combination(s) thereof.
- Clause 16. The process of any of Clauses 1 to 15, further comprising introducing a co-injection particle into the reactor.

Clause 17. The process of any of Clauses 1 to 16, wherein the co-injection particle is introduced into the reactor via the nozzle at a rate of about 1,000 lb/hr to about 3,000 lb/hr.

Clause 18. The process of any of Clauses 1 to 17, further comprising removing the co-injection particle, or product thereof, from the reactor via the second conduit.

Clause 19. The process of any of Clauses 1 to 18, wherein the co-injection particle is calcium oxide and the process includes removing calcium chloride from the reactor via the second conduit.

Clause 20. The process of any of Clauses 1 to 19, wherein the co-injection particle is a zeolite selected from the group consisting of 4A zeolite, 5A zeolite, and combination(s) thereof.

Clause 21. The process of any of Clauses 1 to 20, wherein the co-injection particle has an average diameter of less than 400 microns.

Clause 22. The process of any of Clauses 1 to 21, wherein the co-injection particle has an average diameter of less than 200 microns.

Clause 23. The process of any of Clauses 1 to 22, further comprising:

introducing the co-injection particle, or product thereof, to a cyclone separator via the second conduit;

separating the co-injection particle, or product thereof, from the pyrolysis product using the cyclone separator;

removing the pyrolysis product from the cyclone via a fourth conduit; and

removing the co-injection particle, or product thereof, from the cyclone via fifth conduit.

Clause 24. The process of any of Clauses 1 to 23, further comprising introducing pygas into the reactor.

Clause 25. The process of any of Clauses 1 to 24, wherein introducing the pygas into the reactor is performed via the nozzle at a rate of about 6,000 lb/hr to about 12,000 lb/hr.

- Clause 26. The process of any of Clauses 1 to 25, wherein introducing the plastic melt into the reactor is performed at a rate of about 60,000 lb/hr to about 100,000 lb/hr.
- Clause 27. The process of any of Clauses 1 to 26, wherein removing the catalyst from the reactor comprises removing the catalyst from the reactor via the third conduit disposed at a bottom surface of the reactor.
- Clause 28. The process of any of Clauses 1 to 27, further comprising introducing the catalyst from the reactor to a separator and a regenerator to form a regenerated catalyst.
- Clause 29. The process of any of Clauses 1 to 28, further comprising introducing the regenerated catalyst to the riser or a vessel.
- Clause 30. The process of any of Clauses 1 to 29, wherein the plastic melt is not introduced to the riser.
- Clause 31. The process of any of Clauses 1 to 30, further comprising introducing gas to the riser.
- Clause 32. The process of any of Clauses 1 to 31, wherein pygas is introduced to the riser at a rate of about 9,000 lb/hr to about 11,500 lb/hr.
- Clause 33. The process of any of Clauses 1 to 32, wherein the nozzle coupled with the reactor is further coupled with a plastic melt source, wherein the plastic melt source is not the riser.
- Clause 34. The process of any of Clauses 1 to 33, wherein the plastic melt further comprises a viscosity reducing agent.
- Clause 35. The process of any of Clauses 1 to 34, wherein the viscosity reducing agent comprises an aromatic liquid selected from the group consisting of a benzene, a toluene, a xylene, and combination(s) thereof.
- Clause 36. The process of any of Clauses 1 to 35, wherein pyrolyzing the plastic component is performed at a reactor temperature of about 900 °F to about 1,100 °F and a reactor pressure of about 20 psig to about 40 psig.

- Clause 37. The process of any of Clauses 1 to 36, wherein pygas is introduced into the reactor via the nozzle and the nozzle has an outlet diameter that is smaller than a nozzle interior diameter.
- Clause 38. The process of any of Clauses 1 to 37, wherein introducing the catalyst
5 into the reactor via the first conduit is performed at a catalyst flow rate of about 5.5 tons per minute to about 13.8 tons per minute.
- Clause 39. The process of any of Clauses 1 to 38, wherein introducing the catalyst into the reactor via the first conduit is performed at a catalyst flow rate of about 7.5 tons per minute to about 12.4 tons per minute.
- 10 Clause 40. The process of any of Clauses 1 to 39, wherein the catalyst is disposed in the riser before being introduced into the reactor and the catalyst has a minimum gas fluidization velocity of about 0.4 ft/sec to about 0.6 ft/sec.
- Clause 41. The process of any of Clauses 1 to 40, wherein the catalyst is a zeolite.
- Clause 42. The process of any of Clauses 1 to 41, wherein the zeolite is a ZSM-5
15 zeolite.
- Clause 43. The process of any of Clauses 1 to 42, wherein the catalyst has an average diameter of about 500 microns to about 600 microns.
- Clause 44. The process of any of Clauses 1 to 43, wherein the catalyst has a D1% value of about 400 microns and a D99% value of about 700 microns.
- 20 Clause 45. The process of any of Clauses 1 to 44, wherein the catalyst has a density of about 600 g/l to about 800 g/l.
- Clause 46. The process of any of Clauses 1 to 45, wherein the catalyst has a sphericity of about 0.95 or greater.
- Clause 47. The process of any of Clauses 1 to 46, wherein the catalyst has a zeolite
25 loading amount of about 50 wt% or greater, wherein a remainder balance of the catalyst comprises additive material.

Clause 48. The process of any of Clauses 1 to 47, wherein the catalyst has a zeolite loading amount of about 75 wt% or greater.

Clause 49. The process of any of Clauses 1 to 48, wherein the additive material comprises a binder material.

5 Clause 50. The process of any of Clauses 1 to 49, wherein the reactor comprises a plurality of plates, mesh, or square grid comprising a first row of plates, mesh, or square grid and a second row of plates, mesh, or square grid, wherein the first row is horizontally offset from the second row.

Clause 51. The process of any of Clauses 1 to 50, wherein each plate, mesh, or square
10 of the plurality of plates, mesh, or square grid has a tent shape an angular apex cover in a vertical direction and has one or more openings along the cover.

Clause 52. The process of any of Clauses 1 to 51, wherein the plastic melt has a solids content of about 10 wt% or less.

Clause 53. An apparatus, comprising:

15 a nozzle coupled with a reactor, the nozzle comprising an inlet disposed substantially perpendicular to a horizontal conduit disposed in the nozzle;

a riser coupled with the reactor;

a first outlet conduit disposed at a top 1/2 height of the reactor, the first outlet conduit coupled with a cyclone separator; and

20 a second outlet conduit disposed at a bottom 1/2 height of the reactor, the second outlet conduit coupled with a second separator;

a regenerator coupled with the second separator and the riser.

Clause 54. The apparatus of Clause 53, wherein the reactor comprises a plurality of plates, mesh, or square grid comprising a first row and a second row of plates, mesh, or
25 square grid, wherein the first row is horizontally offset from the second row.

Clause 55. The apparatus of Clauses 53 or 54, wherein the second outlet conduit is disposed at a bottom surface of the reactor.

Clause 56. A process, comprising:

removing a catalyst from a reactor, wherein the catalyst comprises ash;

introducing the catalyst via a conduit to a separator to form a catalyst-rich phase and an ash-rich phase in the separator; and

5 introducing the catalyst-rich phase to a regenerator to form a regenerated catalyst,

wherein the conduit has an end disposed within the separator at a 1/4 to 3/4 height of the separator and the end comprises a plurality of outlets.

Clause 57. The process of any of Clauses 1 to 52 or 56, wherein the conduit is disposed at an angle of about 30° to about 90° relative to a substantially vertical side of the separator.

Clause 58. The process of any of Clauses 1 to 52, 56, or 57, further comprising introducing a gas to the conduit.

Clause 59. The process of any of Clauses 1 to 52 or 56 to 58, wherein the catalyst introduced to the separator has a temperature of about 950 °F to about 1,050 °F when introduced to the separator and is introduced to the separator at a rate of about 1.3 million lbs/hr to about 1.7 million lbs/hr.

Clause 60. The process of any of Clauses 1 to 52 or 56 to 59, further comprising introducing a gas into the separator via a second conduit at a rate of about 0.3 ft/s to about 0.7 ft/s, wherein the gas has a temperature of about 150 °F to about 1050 °F.

20 Clause 61. The process of any of Clauses 1 to 52 or 56 to 60, wherein forming the catalyst-rich phase and the ash-rich phase in the separator is performed at a pressure of about 25 psig to about 40 psig and a temperature of about 850 °F to about 1,050 °F.

Clause 62. The process of any of Clauses 1 to 52 or 56 to 61, wherein the catalyst introduced into the reactor comprises a zeolite and sand and the catalyst introduced from the conduit to the separator comprises the zeolite, the sand, and the ash.

Clause 63. The process of any of Clauses 1 to 52 or 56 to 62, wherein introducing the catalyst from the conduit to the separator further forms a sand-rich phase in the separator,

the process further comprising removing the sand-rich phase from the separator via a second conduit.

Clause 64. The process of any of Clauses 1 to 52 or 56 to 63, further comprising introducing the ash-rich phase to a second separator to form a second catalyst-rich phase and a second ash-rich phase.

Clause 65. The process of Clause 64, wherein the second separator is a stage volume within the first separator.

Clause 66. A process, comprising:
introducing a plastic melt comprising a plastic component into a reactor via a nozzle coupled with the reactor;
introducing a catalyst into the reactor via a first conduit coupling the reactor with a riser or regenerator;
pyrolyzing the plastic component to form a pyrolysis product;
removing the pyrolysis product from the reactor via a second conduit disposed at a top 1/2 height of the reactor; and
removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor.

Clause 67. The process of Clause 66, further comprising sorting a bale comprising the plastic component into a plurality of portions, wherein at least one of the portions comprises the plastic component.

Clause 68. The process of Clauses 66 or 67, wherein the reactor is a bubbling bed reactor and the plastic melt has a temperature of about 900 °F to about 1,100 °F during introducing the plastic melt into the reactor.

Clause 69. The process of any of Clauses 66 to 68, wherein the plastic component is selected from the group consisting of polyethylene, polypropylene, polystyrene, polyethylene terephthalate, polyvinylchloride, and combination(s) thereof.

Clause 70. The process of any of Claims 66 to 69, wherein the pyrolysis product comprises an organic compound selected from the group consisting of an ethylene, a propylene, a butene, a benzene, a toluene, a xylene, and combination(s) thereof.

- 5 Clause 71. The process of any of Claims 66 to 70, further comprising introducing a co-injection particle into the reactor.

Clause 72. The process of any of Claims 66 to 71, wherein the co-injection particle is introduced into the reactor via the nozzle at a rate of about 1,000 lb/hr to about 3,000
10 lb/hr.

Clause 73. The process of any of Claims 66 to 72, further comprising removing the co-injection particle, or product thereof, from the reactor via the second conduit.

- 15 Clause 74. The process of any of Claims 66 to 73, wherein the co-injection particle is calcium oxide and the process includes removing calcium chloride from the reactor via the second conduit.

Clause 75. The process of any of Claims 66 to 74, wherein the co-injection particle
20 is a zeolite selected from the group consisting of 4A zeolite, 5A zeolite, and combination(s) thereof.

Clause 76. The process of any of Claims 66 to 75, wherein the co-injection particle has an average diameter of less than 400 microns.

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Clause 77. The process of any of Claims 66 to 76, wherein the co-injection particle has an average diameter of less than 200 microns.

- Clause 78. The process of any of Claims 66 to 77, further comprising:
30 introducing the co-injection particle, or product thereof, to a cyclone separator via the second conduit;
 separating the co-injection particle, or product thereof, from the pyrolysis product using the cyclone separator;
 removing the pyrolysis product from the cyclone via a fourth conduit; and

removing the co-injection particle, or product thereof, from the cyclone via fifth conduit.

Clause 79. The process of any of Clauses 66 to 78, further comprising introducing
5 pygas into the reactor.

Clause 80. The process of any of Clauses 66 to 79, wherein introducing the pygas into the reactor is performed via the nozzle at a rate of about 3,000 lb/hr to about 5,000 lb/hr.

10 Clause 81. The process of any of Clauses 66 to 80, wherein introducing the plastic melt into the reactor is performed at a rate of about 30,000 lb/hr to about 50,000 lb/hr.

Clause 82. The process of any of Clauses 66 to 81, wherein removing the catalyst from the reactor comprises removing the catalyst from the reactor via the third conduit
15 disposed at a bottom surface of the reactor.

Clause 83. The process of any of Clauses 66 to 82, further comprising introducing the catalyst from the reactor to a separator and a regenerator to form a regenerated catalyst.

20 Clause 84. The process of any of Clauses 66 to 83, further comprising introducing the regenerated catalyst to the riser or a vessel.

Clause 85. The process of any of Clauses 66 to 84, wherein the plastic melt is not introduced to the riser.
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Clause 86. The process of any of Clauses 66 to 85, further comprising introducing gas to the riser.

Clause 87. The process of any of Clauses 66 to 86, wherein pygas is introduced to the
30 riser at a rate of about 9,000 lb/hr to about 11,500 lb/hr.

Clause 88. The process of any of Clauses 66 to 87, wherein the nozzle coupled with the reactor is further coupled with a plastic melt source, wherein the plastic melt source is not the riser.

Clause 89. The process of any of Clauses 66 to 88, wherein the plastic melt further comprises a viscosity reducing agent.

Clause 90. The process of any of Clauses 66 to 89, wherein the viscosity reducing agent comprises an aromatic liquid selected from the group consisting of a benzene, a toluene, a xylene, and combination(s) thereof.

Clause 91. The process of any of Clauses 66 to 25, wherein pyrolyzing the plastic component is performed at a reactor temperature of about 900 °F to about 1,100 °F and a reactor pressure of about 20 psig to about 40 psig.

Clause 92. The process of any of Clauses 66 to 91, wherein pygas is introduced into the reactor via the nozzle and the nozzle has an outlet diameter that is smaller than a nozzle interior diameter.

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Clause 93. The process of any of Clauses 66 to 92, wherein introducing the catalyst into the reactor via the first conduit is performed at a catalyst flow rate of about 2.5 tons per minute to about 8.8 tons per minute.

Clause 94. The process of any of Clauses 66 to 93, wherein introducing the catalyst into the reactor via the first conduit is performed at a catalyst flow rate of about 3.5 tons per minute to about 4.4 tons per minute.

Clause 95. The process of any of Clauses 66 to 94, wherein the catalyst disposed in the riser has a minimum gas fluidization velocity of about 0.4 ft/sec to about 0.6 ft/sec.

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Clause 96. The process of any of Clauses 66 to 95, wherein the catalyst is a zeolite.

Clause 97. The process of any of Clauses 66 to 96, wherein the zeolite is a ZSM-5 zeolite.

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Clause 98. The process of any of Clauses 66 to 97, wherein the catalyst has an average diameter of about 500 microns to about 600 microns.

Clause 99. The process of any of Clauses 66 to 98, wherein the catalyst has a D1% value of about 400 microns and a D99% value of about 700 microns.

Clause 100. The process of any of Clauses 66 to 99, wherein the catalyst has a density
5 of about 600 g/l to about 800 g/l.

Clause 101. The process of any of Clauses 66 to 100, wherein the catalyst has a sphericity of about 0.95 or greater.

10 Clause 102. The process of any of Clauses 66 to 101, wherein the catalyst has a zeolite loading amount of about 50 wt% or greater, wherein a remainder balance of the catalyst comprises additive material.

Clause 103. The process of any of Clauses 66 to 102, wherein the catalyst has a zeolite
15 loading amount of about 75 wt% or greater.

Clause 104. The process of any of Clauses 66 to 103, wherein the additive material comprises a binder material.

20 Clause 105. The process of any of Clauses 66 to 104, wherein the reactor comprises a plurality of plates, mesh, or square grid comprising a first row of plates, mesh, or square grid and a second row of plates, mesh, or square grid, wherein the first row is horizontally offset from the second row.

25 Clause 106. The process of any of Clauses 66 to 105, wherein each plate, mesh, or square of the plurality of plates, mesh, or square grid has a tent shape an angular apex cover in a vertical direction and has one or more openings along the cover.

Clause 107. The process of any of Clauses 66 to 106, wherein the plastic melt has a
30 solids content of about 10 wt% or less.

[0081] Overall, apparatus and processes of the present disclosure provide high throughput of pyrolysis, such as plastic pyrolysis, to form pyrolysis products. Processes can be performed as a single-stage process, providing higher yields than conventional processes for processing waste plastic. Apparatus and processes of the present disclosure

provide elutriation of char, attrited catalyst, and co-injection material such that spent catalyst can be easily regenerated, providing improved throughput of plastic pyrolysis in addition to higher purity of recycled catalyst to the reactor. In addition, use of catalyst having a narrow size distribution and larger average diameter than the co-injection material provides the elutriation of co-injection material. In addition, use of catalyst having a large average diameter, in addition to a reactor configured to provide bubble control, provides reduced plugging and wear of vessel conduits, valves, and other apparatus components, providing maintained integrity and a longer life cycle of apparatus of the present disclosure. In addition, use of a separator of the present disclosure provides improved throughput of pyrolysis products because of improved separation of spent catalyst from components such as ash. Throughput is improved using the separator because, *inter alia*, the time intervals between apparatus shutdown can be lengthened because catalyst can remain viable (*e.g.*, the catalyst is regenerated). A separator of the present disclosure can also provide improved regeneration of spent catalyst (because ash is removed in the separator), which further improves throughput and yield of pyrolysis products.

[0082] The term "pyrolysis" includes an on-average endothermic reaction for converting molecules into (i) atoms and/or (ii) molecules of lesser molecular weight, and/or optionally (iii) molecules of greater molecular weight, *e.g.*, processes for forming C₂-C₁₂ unsaturates such as ethylene, propylene, acetylene, benzene, toluene, xylene, or combination(s) thereof.

[0083] The term "catalyst activity" includes the weight of volatile matter converted per catalyst weight over a given amount of time.

[0084] The term "spent catalyst" includes any catalyst that has less activity at the same reaction conditions (*e.g.*, temperature, pressure, inlet flows) than the catalyst had when it was originally exposed to the process. This can be due to a number of reasons, several non-limiting examples of causes of catalyst deactivation are coking or char sorption or accumulation, metals sorption or accumulation, attrition, morphological changes including changes in pore sizes, cation or anion substitution, and/or chemical or compositional changes. Spent catalyst can include an amount of catalyst that is not spent (*e.g.*, has not been deactivated) in addition to catalyst that is spent.

[0085] The term "regenerated catalyst" includes a catalyst that had become spent, as defined above, and was then subjected to a process that increased its activity, as defined above, to a level greater than it had as a spent catalyst. This may involve, for example,

reversing transformations or removing contaminants outlined above as possible causes of reduced activity. The regenerated catalyst may have an activity greater than or equal to the fresh catalyst (typically referred to herein as “catalyst” unless otherwise noted), but typically, regenerated catalyst has an activity that is between the spent and fresh catalyst.

5 [0086] The term “pygas” includes a hydrocarbon fluid (gas or liquid) that is derived from waste plastic material. Pygas can exist as either a raw effluent stream from a reactor or a refined material recycled via a recycle stream for use of fluidization or further conversion in the reactor system.

[0087] The term “ash” includes ash that is removed from the reactor and separated
10 from other material. The ash is a solid phase that is considered not part of the size fraction of the catalyst that is circulating through the apparatus. Ash can be attrited catalyst fines, char from plastics, and/or co-injected materials which could be metal-oxides or catalyst by material.

[0088] Although embodiments of the present disclosure have been described for
15 pyrolysis of plastic feeds, embodiments of the present disclosure where applicable might be used in any other suitable apparatus or process. For example, a separator of the present disclosure (*e.g.*, separator **106**) may be utilized in any suitable apparatus or process, such as a solid-solid separation incorporated with conventional petrochemical processes, such as fluidized catalytic cracking of crude oil and the like.

20 [0089] The phrases, unless otherwise specified, “consists essentially of” and “consisting essentially of” do not exclude the presence of other steps, elements, or materials, whether or not, specifically mentioned in this specification, so long as such steps, elements, or materials, do not affect the basic and novel characteristics of the present disclosure, additionally, they do not exclude impurities and variances normally
25 associated with the elements and materials used.

[0090] For the sake of brevity, only certain ranges are explicitly disclosed herein. However, ranges from any lower limit may be combined with any upper limit to recite a range not explicitly recited, as well as, ranges from any lower limit may be combined with any other lower limit to recite a range not explicitly recited, in the same way, ranges
30 from any upper limit may be combined with any other upper limit to recite a range not explicitly recited. Additionally, within a range includes every point or individual value between its end points even though not explicitly recited. Thus, every point or individual value may serve as its own lower or upper limit combined with any other point or individual value or any other lower or upper limit, to recite a range not explicitly recited.

[0091] All numerical values within the detailed description herein are modified by “about” the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0092] All documents described herein are incorporated by reference herein, including any priority documents and or testing procedures to the extent they are not inconsistent with this text. As is apparent from the foregoing general description and the specific embodiments, while forms of the present disclosure have been illustrated and described, various modifications can be made without departing from the spirit and scope of the present disclosure. Accordingly, it is not intended that the present disclosure be limited thereby. Likewise, the term “comprising” is considered synonymous with the term “including” for purposes of United States law. Likewise whenever a composition, an element or a group of elements is preceded with the transitional phrase “comprising,” it is understood that we also contemplate the same composition or group of elements with transitional phrases “consisting essentially of,” “consisting of,” “selected from the group of consisting of,” or “is” preceding the recitation of the composition, element, or elements and vice versa.

[0093] While the present disclosure has been described with respect to a number of embodiments and examples, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope and spirit of the present disclosure.

CLAIMS

We claim:

1. A process, comprising:
 - 5 introducing a plastic melt comprising a plastic component into a reactor via a nozzle coupled with the reactor;
 - introducing a catalyst into the reactor via a first conduit coupling the reactor with a riser or a regenerator;
 - pyrolyzing the plastic component to form a pyrolysis product;
 - 10 removing the pyrolysis product from the reactor via a second conduit disposed at a top 1/2 height of the reactor;
 - removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor, wherein the catalyst removed from the reactor comprises ash; and
 - introducing the catalyst from the third conduit to a separator to form a catalyst-
15 rich phase and an ash-rich phase in the separator.
2. The process of claim 1, wherein the third conduit is disposed at an angle of about 30° to about 90° relative to a substantially vertical side of the separator.
- 20 3. The process of claim 2, further comprising introducing a gas to the third conduit.
4. The process of claim 2, wherein the catalyst introduced to the separator has a temperature of about 950 °F to about 1,050 °F when introduced to the separator and is introduced to the separator at a rate of about 1.3 million lbs/hr to about 1.7 million lbs/hr.
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5. The process of claim 1, wherein the third conduit has an end disposed within the separator and the end comprises a plurality of outlets.
6. The process of claim 5, wherein the end of the third conduit is disposed at a 1/4
30 to 3/4 height of the separator.
7. The process of claim 1, further comprising introducing a gas into the separator via a fourth conduit at a rate of about 0.3 ft/s to about 0.7 ft/s, wherein the gas has a temperature of about 150 °F to about 1050 °F.

8. The process of claim 1, wherein forming the catalyst-rich phase and the ash-rich phase in the separator is performed at a pressure of about 25 psig to about 40 psig and a temperature of about 850 °F to about 1,050 °F.

5 9. A process, comprising:
removing a catalyst from a reactor, wherein the catalyst comprises ash;
introducing the catalyst via a conduit to a separator to form a catalyst-rich phase
and an ash-rich phase in the separator; and
introducing the catalyst-rich phase to a regenerator to form a regenerated catalyst,
10 wherein the conduit has an end disposed within the separator at a 1/4 to 3/4 height
of the separator and the end comprises a plurality of outlets.

10. The process of claim 9, wherein the conduit is disposed at an angle of about 30°
to about 90° relative to a substantially vertical side of the separator.

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11. The process of claim 9, wherein the catalyst introduced to the separator has a
temperature of about 950 °F to about 1,050 °F when introduced to the separator and is
introduced to the separator at a rate of about 1.3 million lbs/hr to about 1.7 million lbs/hr.

20 12. The process of claim 9, further comprising introducing a gas into the separator via
a second conduit at a rate of about 0.3 ft/s to about 0.7 ft/s, wherein the gas has a
temperature of about 150 °F to about 1050 °F.

25 13. The process of claim 9, wherein forming the catalyst-rich phase and the ash-rich
phase in the separator is performed at a pressure of about 25 psig to about 40 psig and a
temperature of about 850 °F to about 1,050 °F.

14. A process, comprising:
introducing a plastic melt comprising a plastic component into a reactor via a
30 nozzle coupled with the reactor;
introducing a catalyst into the reactor via a first conduit coupling the reactor with
a riser or regenerator;
pyrolyzing the plastic component to form a pyrolysis product;
removing the pyrolysis product from the reactor via a second conduit disposed at
35 a top 1/2 height of the reactor; and

removing the catalyst from the reactor via a third conduit disposed at a bottom 1/2 height of the reactor.

15. The process of claim 14, further comprising sorting a bale comprising the plastic component into a plurality of portions, wherein at least one of the portions comprises the plastic component.

16. The process of claim 14, wherein the reactor is a bubbling bed reactor and the plastic melt has a temperature of about 900 °F to about 1,100 °F during introducing the plastic melt into the reactor.

17. The process of claim 14, wherein the plastic component is selected from the group consisting of polyethylene, polypropylene, polystyrene, polyethylene terephthalate, polyvinylchloride, and combination(s) thereof.

18. The process of claim 17, wherein the pyrolysis product comprises an organic compound selected from the group consisting of an ethylene, a propylene, a butene, a benzene, a toluene, a xylene, and combination(s) thereof.

19. The process of claim 14, further comprising introducing a co-injection particle into the reactor, wherein the co-injection particle is calcium oxide and the process includes removing calcium chloride from the reactor via the second conduit.

20. The process of claim 14, wherein the catalyst is a zeolite having an average diameter of about 500 microns to about 600 microns.