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(54) **METHANE CONVERSION APPARATUS AND PROCESS USING A SUPERSONIC FLOW REACTOR**

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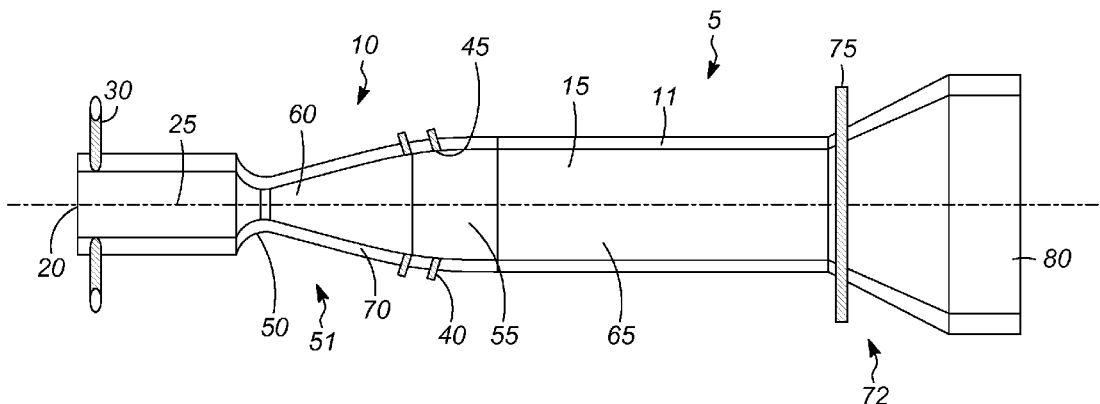
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(57) **ABSTRACT**

Apparatus and methods are provided for converting methane in a feed stream to acetylene. A hydrocarbon stream is introduced into a supersonic reactor and pyrolyzed to convert at least a portion of the methane to acetylene. The reactor effluent stream may be treated to convert acetylene to another hydrocarbon process.



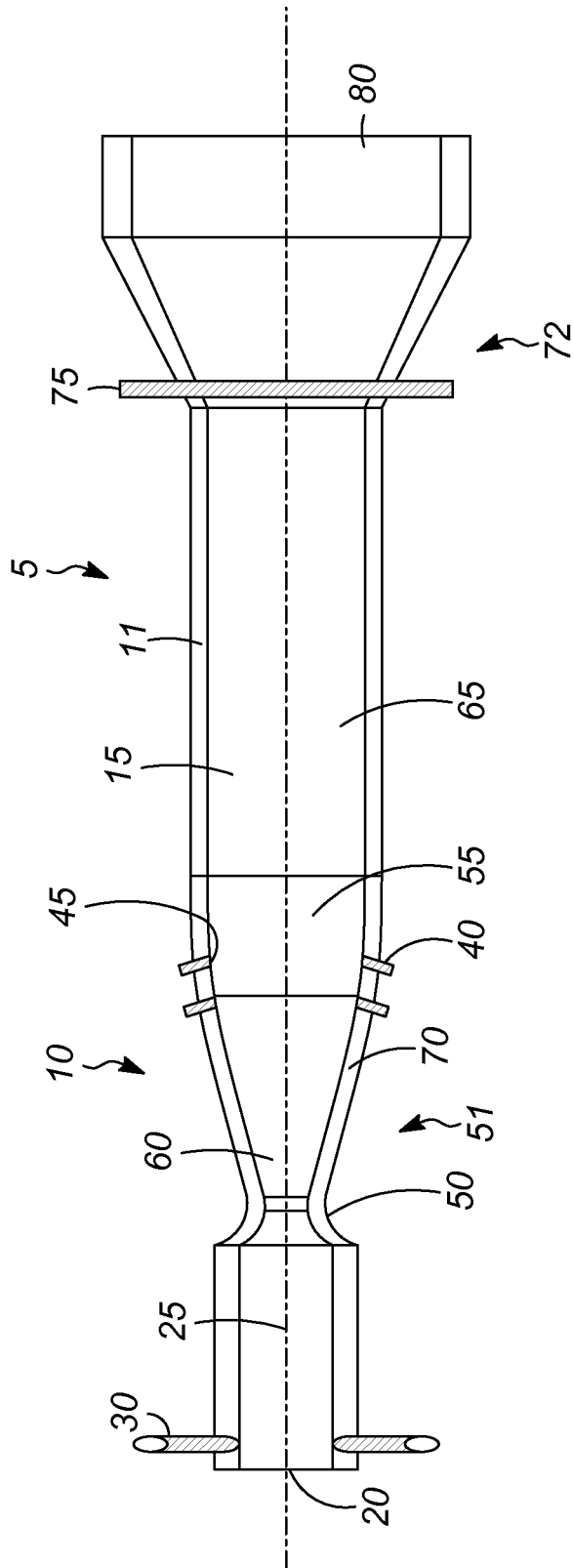


FIG. 1

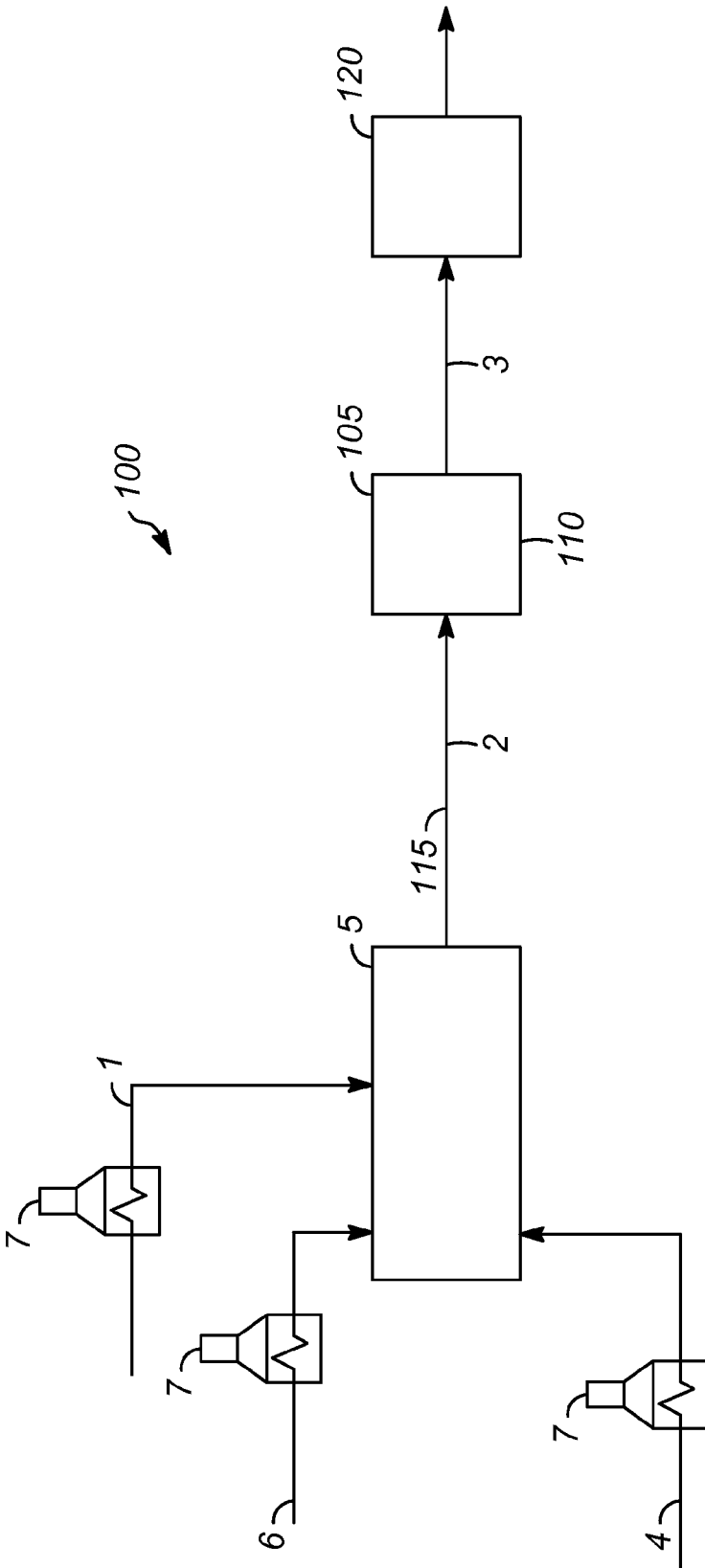


FIG. 2

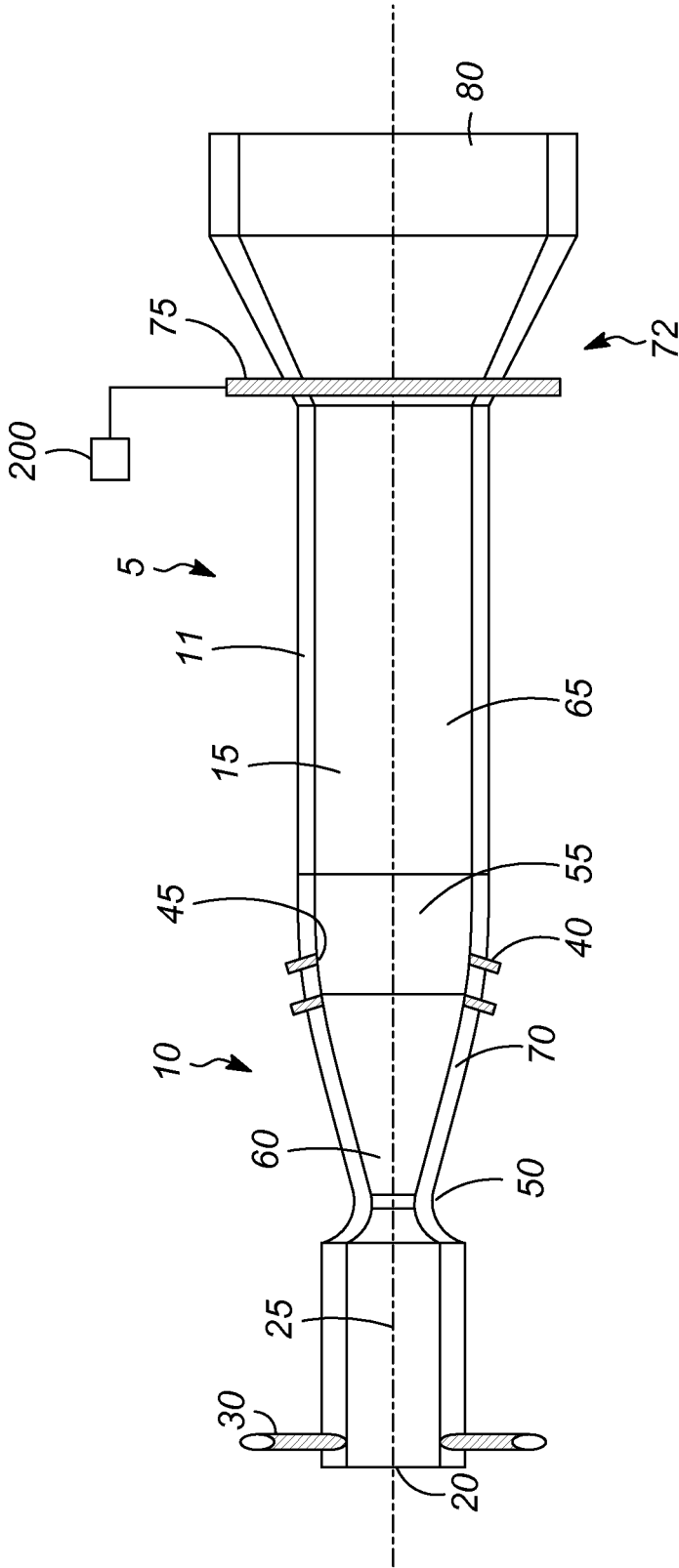


FIG. 3

METHANE CONVERSION APPARATUS AND PROCESS USING A SUPERSONIC FLOW REACTOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from Provisional Application No. 61/691,305 filed Aug. 21, 2012, the contents of which are hereby incorporated by reference in its entirety.

FIELD

[0002] Apparatus and methods are disclosed for converting methane in a hydrocarbon stream to acetylene using a supersonic flow reactor.

BACKGROUND

[0003] Light olefin materials, including ethylene and propylene, represent a large portion of the worldwide demand in the petrochemical industry. Light olefins are used in the production of numerous chemical products via polymerization, oligomerization, alkylation and other well-known chemical reactions. These light olefins are essential building blocks for the modern petrochemical and chemical industries. Producing large quantities of light olefin material in an economical manner, therefore, is a focus in the petrochemical industry. The main source for these materials in present day refining is the steam cracking of petroleum feeds.

[0004] The cracking of hydrocarbons brought about by heating a feedstock material in a furnace has long been used to produce useful products, including for example, olefin products. For example, ethylene, which is among the more important products in the chemical industry, can be produced by the pyrolysis of feedstocks ranging from light paraffins, such as ethane and propane, to heavier fractions such as naphtha. Typically, the lighter feedstocks produce higher ethylene yields (50-55% for ethane compared to 25-30% for naphtha); however, the cost of the feedstock is more likely to determine which is used. Historically, naphtha cracking has provided the largest source of ethylene, followed by ethane and propane pyrolysis, cracking, or dehydrogenation. Due to the large demand for ethylene and other light olefinic materials, however, the cost of these traditional feeds has steadily increased.

[0005] Energy consumption is another cost factor impacting the pyrolytic production of chemical products from various feedstocks. Over the past several decades, there have been significant improvements in the efficiency of the pyrolysis process that have reduced the costs of production. In a typical or conventional pyrolysis plant, a feedstock passes through a plurality of heat exchanger tubes where it is heated externally to a pyrolysis temperature by the combustion products of fuel oil or natural gas and air. One of the more important steps taken to minimize production costs has been the reduction of the residence time for a feedstock in the heat exchanger tubes of a pyrolysis furnace. Reduction of the residence time increases the yield of the desired product while reducing the production of heavier by-products that tend to foul the pyrolysis tube walls. However, there is little room left to improve the residence times or overall energy consumption in traditional pyrolysis processes.

[0006] More recent attempts to decrease light olefin production costs include utilizing alternative processes and/or feed streams. In one approach, hydrocarbon oxygenates and

more specifically methanol or dimethylether (DME) are used as an alternative feedstock for producing light olefin products. Oxygenates can be produced from available materials such as coal, natural gas, recycled plastics, various carbon waste streams from industry and various products and by-products from the agricultural industry. Making methanol and other oxygenates from these types of raw materials is well established and typically includes one or more generally known processes such as the manufacture of synthesis gas using a nickel or cobalt catalyst in a steam reforming step followed by a methanol synthesis step at relatively high pressure using a copper-based catalyst.

[0007] Once the oxygenates are formed, the process includes catalytically converting the oxygenates, such as methanol, into the desired light olefin products in an oxygenate to olefin (OTO) process. Techniques for converting oxygenates, such as methanol to light olefins (MTO), are described in U.S. Pat. No. 4,387,263, which discloses a process that utilizes a catalytic conversion zone containing a zeolitic type catalyst. U.S. Pat. No. 4,587,373 discloses using a zeolitic catalyst like ZSM-5 for purposes of making light olefins. U.S. Pat. Nos. 5,095,163; 5,126,308 and 5,191,141 on the other hand, disclose an MTO conversion technology utilizing a non-zeolitic molecular sieve catalytic material, such as a metal aluminophosphate (ELAPO) molecular sieve. OTO and MTO processes, while useful, utilize an indirect process for forming a desired hydrocarbon product by first converting a feed to an oxygenate and subsequently converting the oxygenate to the hydrocarbon product. This indirect route of production is often associated with energy and cost penalties, often reducing the advantage gained by using a less expensive feed material.

[0008] Recently, attempts have been made to use pyrolysis to convert natural gas to ethylene. U.S. Pat. No. 7,183,451 discloses heating natural gas to a temperature at which a fraction is converted to hydrogen and a hydrocarbon product such as acetylene or ethylene. The product stream is then quenched to stop further reaction and subsequently reacted in the presence of a catalyst to form liquids to be transported. The liquids ultimately produced include naphtha, gasoline, or diesel. While this method may be effective for converting a portion of natural gas to acetylene or ethylene, it is estimated that this approach will provide only about a 40% yield of acetylene from a methane feed stream. While it has been identified that higher temperatures in conjunction with short residence times can increase the yield, technical limitations prevent further improvement to this process in this regard.

[0009] While the foregoing traditional pyrolysis systems provide solutions for converting ethane and propane into other useful hydrocarbon products, they have proven either ineffective or uneconomical for converting methane into these other products, such as, for example ethylene. While MTO technology is promising, these processes can be expensive due to the indirect approach of forming the desired product. Due to continued increases in the price of feeds for traditional processes, such as ethane and naphtha, and the abundant supply and corresponding low cost of natural gas and other methane sources available, for example the more recent accessibility of shale gas, it is desirable to provide commercially feasible and cost effective ways to use methane as a feed for producing ethylene and other useful hydrocarbons.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a side cross-sectional view of a supersonic reactor in accordance with various embodiments described herein;

[0011] FIG. 2 is a schematic view of a system for converting methane into acetylene and other hydrocarbon products in accordance with various embodiments described herein;

[0012] FIG. 3 is a side cross-sectional view of a supersonic reactor in accordance with various embodiments described herein.

DETAILED DESCRIPTION

[0013] One proposed alternative to the previous methods of producing olefins that has not gained much commercial traction includes passing a hydrocarbon feedstock into a supersonic reactor and accelerating it to supersonic speed to provide kinetic energy that can be transformed into heat to enable an endothermic pyrolysis reaction to occur. Variations of this process are set out in U.S. Pat. Nos. 4,136,015 and 4,724,272, and Russian Patent No. SU 392723A. These processes include combusting a feedstock or carrier fluid in an oxygen-rich environment to increase the temperature of the feed and accelerate the feed to supersonic speeds. A shock wave is created within the reactor to initiate pyrolysis or cracking of the feed.

[0014] More recently, U.S. Pat. Nos. 5,219,530 and 5,300,216 have suggested a similar process that utilizes a shock wave reactor to provide kinetic energy for initiating pyrolysis of natural gas to produce acetylene. More particularly, this process includes passing steam through a heater section to become superheated and accelerated to a nearly supersonic speed. The heated fluid is conveyed to a nozzle which acts to expand the carrier fluid to a supersonic speed and lower temperature. An ethane feedstock is passed through a compressor and heater and injected by nozzles to mix with the supersonic carrier fluid to turbulently mix together at a speed of about Mach 2.8 and a temperature of about 427 C. The temperature in the mixing section remains low enough to restrict premature pyrolysis. The shockwave reactor includes a pyrolysis section with a gradually increasing cross-sectional area where a standing shock wave is formed by back pressure in the reactor due to flow restriction at the outlet. The shock wave rapidly decreases the speed of the fluid, correspondingly rapidly increasing the temperature of the mixture by converting the kinetic energy into heat. This immediately initiates pyrolysis of the ethane feedstock to convert it to other products. A quench heat exchanger then receives the pyrolyzed mixture to quench the pyrolysis reaction.

[0015] Methods and apparatus for converting hydrocarbon components in methane feed streams using a supersonic reactor are generally disclosed. As used herein, the term "methane feed stream" includes any feed stream comprising methane. The methane feed streams provided for processing in the supersonic reactor generally include methane and form at least a portion of a process stream. The apparatus and methods presented herein convert at least a portion of the methane to a desired product hydrocarbon compound to produce a product stream having a higher concentration of the product hydrocarbon compound relative to the feed stream.

[0016] The term "hydrocarbon stream" as used herein refers to one or more streams that provide at least a portion of the methane feed stream entering the supersonic reactor as described herein or are produced from the supersonic reactor

from the methane feed stream, regardless of whether further treatment or processing is conducted on such hydrocarbon stream. With reference to the example illustrated in FIG. 2, the "hydrocarbon stream" may include the methane feed stream 1, a supersonic reactor effluent stream 2, a desired product stream 3 exiting a downstream hydrocarbon conversion process or any intermediate or by-product streams formed during the processes described herein. The hydrocarbon stream may be carried via a process stream line 115, as shown in FIG. 2, which includes lines for carrying each of the portions of the process stream described above. The term "process stream" as used herein includes the "hydrocarbon stream" as described above, as well as it may include a carrier fluid stream, a fuel stream 4, an oxygen source stream 6, or any streams used in the systems and the processes described herein. The process stream may be carried via a process stream line 115, which includes lines for carrying each of the portions of the process stream described above. As illustrated in FIG. 2, any of methane feed stream 1, fuel stream 4, and oxygen source stream 6, may be preheated, for example, by one or more heaters 7.

[0017] Prior attempts to convert light paraffin or alkane feed streams, including ethane and propane feed streams, to other hydrocarbons using supersonic flow reactors have shown promise in providing higher yields of desired products from a particular feed stream than other more traditional pyrolysis systems. Specifically, the ability of these types of processes to provide very high reaction temperatures with very short associated residence times offers significant improvement over traditional pyrolysis processes. It has more recently been realized that these processes may also be able to convert methane to acetylene and other useful hydrocarbons, whereas more traditional pyrolysis processes were incapable or inefficient for such conversions.

[0018] The majority of previous work with supersonic reactor systems, however, has been theoretical or research based, and thus has not addressed problems associated with practicing the process on a commercial scale. In addition, many of these prior disclosures do not contemplate using supersonic reactors to effectuate pyrolysis of a methane feed stream, and tend to focus primarily on the pyrolysis of ethane and propane. One problem that has recently been identified with adopting the use of a supersonic flow reactor for light alkane pyrolysis, and more specifically the pyrolysis of methane feeds to form acetylene and other useful products therefrom, includes effectively quenching the hot stream in the supersonic reactor. More particularly, as described below, if the methane is heated above a pyrolysis temperature for too long, the pyrolysis reaction may continue converting a large portion of the feed into unwanted products, such as coke or soot. Thus, it is desired to effectively cool the stream after it has reacted at the pyrolysis temperature. This is further made difficult due to the very high temperatures present in the supersonic reactor. Because temperatures in the reactor may reach 3000 C and higher, it may be difficult to quickly and effectively cool the fluid. Further, the high temperatures and supersonic flowrates present in the reactor chamber may cause melting or other deterioration of any equipment, including nozzles, used for quenching the stream.

[0019] More specifically, the carrier stream and feed stream may travel through the reactor at supersonic speeds, which can quickly erode many materials that could be used to form the equipment used for quenching. Moreover, certain substances and contaminants that may be present in the hydro-

carbon stream can cause corrosion, oxidation, and/or reduction of the reactor walls or shell and other equipment or components of the reactor. Such components causing corrosion, oxidation, or reduction problems may include, for example hydrogen sulfide, water, methanethiol, arsine, mercury vapor, carbidization via reaction with the fuel itself, or hydrogen embrittlement.

[0020] In accordance with various embodiments disclosed herein, therefore, apparatus and methods for converting methane in hydrocarbon streams to acetylene and other products are provided. Apparatus in accordance herewith, and the use thereof, have been identified to improve the overall process for the pyrolysis of light alkane feeds, including methane feeds, to acetylene and other useful products. The apparatus and processes described herein also beneficially improve the ability to effectively decrease the temperature of the stream passing through the supersonic reactor to control the pyrolysis reaction occurring therein and further provides for the apparatus and associated components and equipment of the quench process to withstand degradation and possible failure due to extreme operating conditions within the reactor.

[0021] In accordance with one approach, the apparatus and methods disclosed herein are used to treat a hydrocarbon process stream to convert at least a portion of methane in the hydrocarbon process stream to acetylene. The hydrocarbon process stream described herein includes the methane feed stream provided to the system, which includes methane and may also include ethane or propane. The methane feed stream may also include combinations of methane, ethane, and propane at various concentrations and may also include other hydrocarbon compounds as well as contaminants. In one approach, the hydrocarbon feed stream includes natural gas. The natural gas may be provided from a variety of sources including, but not limited to, gas fields, oil fields, coal fields, fracking of shale fields, biomass, and landfill gas. In another approach, the methane feed stream can include a stream from another portion of a refinery or processing plant. For example, light alkanes, including methane, are often separated during processing of crude oil into various products and a methane feed stream may be provided from one of these sources. These streams may be provided from the same refinery or different refinery or from a refinery off gas. The methane feed stream may include a stream from combinations of different sources as well.

[0022] In accordance with the processes and systems described herein, a methane feed stream may be provided from a remote location or at the location or locations of the systems and methods described herein. For example, while the methane feed stream source may be located at the same refinery or processing plant where the processes and systems are carried out, such as from production from another on-site hydrocarbon conversion process or a local natural gas field, the methane feed stream may be provided from a remote source via pipelines or other transportation methods. For example a feed stream may be provided from a remote hydrocarbon processing plant or refinery or a remote natural gas field, and provided as a feed to the systems and processes described herein. Initial processing of a methane stream may occur at the remote source to remove certain contaminants from the methane feed stream. Where such initial processing occurs, it may be considered part of the systems and processes described herein, or it may occur upstream of the systems and processes described herein. Thus, the methane feed stream provided for the systems and processes described herein may

have varying levels of contaminants depending on whether initial processing occurs upstream thereof.

[0023] In one example, the methane feed stream has a methane content ranging from about 65 mol-% to about 100 mol-%. In another example, the concentration of methane in the hydrocarbon feed ranges from about 80 mol-% to about 100 mol-% of the hydrocarbon feed.

[0024] In yet another example, the concentration of methane ranges from about 90 mol-% to about 100 mol-% of the hydrocarbon feed.

[0025] In one example, the concentration of ethane in the methane feed ranges from about 0 mol-% to about 35 mol-% and in another example from about 0 mol-% to about 10 mol-%. In one example, the concentration of propane in the methane feed ranges from about 0 mol-% to about 5 mol-% and in another example from about 0 mol-% to about 1 mol-%.

[0026] The methane feed stream may also include heavy hydrocarbons, such as aromatics, paraffinic, olefinic, and naphthenic hydrocarbons. These heavy hydrocarbons if present will likely be present at concentrations of between about 0 mol-% and about 100 mol-%. In another example, they may be present at concentrations of between about 0 mol-% and 10 mol-% and may be present at between about 0 mol-% and 2 mol-%.

[0027] The apparatus and method for forming acetylene from the methane feed stream described herein utilizes a supersonic flow reactor for pyrolyzing methane in the feed stream to form acetylene. The supersonic flow reactor may include one or more reactors capable of creating a supersonic flow of a carrier fluid and the methane feed stream and expanding the carrier fluid to initiate the pyrolysis reaction. In one approach, the process may include a supersonic reactor as generally described in U.S. Pat. No. 4,724,272, which is incorporated herein by reference, in its entirety. In another approach, the process and system may include a supersonic reactor such as described as a "shock wave" reactor in U.S. Pat. Nos. 5,219,530 and 5,300,216, which are incorporated herein by reference, in their entirety. In yet another approach, the supersonic reactor described as a "shock wave" reactor may include a reactor such as described in "Supersonic Injection and Mixing in the Shock Wave Reactor" Robert G. Cerff, University of Washington Graduate School, 2010.

[0028] While a variety of supersonic reactors may be used in the present process, an exemplary reactor **5** is illustrated in FIG. 1. Referring to FIG. 1, the supersonic reactor **5** includes a reactor vessel **10** generally defining a reactor chamber **15**. While the reactor **5** is illustrated as a single reactor, it should be understood that it may be formed modularly or as separate vessels. If formed modularly or as separate components, the modules or separate components of the reactor may be joined together permanently or temporarily, or may be separate from one another with fluids contained by other means, such as, for example, differential pressure adjustment between them. A combustion zone or chamber **25** is provided for combusting a fuel to produce a carrier fluid with the desired temperature and flowrate. The reactor **5** may optionally include a carrier fluid inlet **20** for introducing a supplemental carrier fluid into the reactor. One or more fuel injectors **30** are provided for injecting a combustible fuel, for example hydrogen, into the combustion chamber **25**. The same or other injectors may be provided for injecting an oxygen source into the combustion chamber **25** to facilitate combustion of the fuel. The fuel and oxygen are combusted to produce a hot carrier fluid stream

typically having a temperature of from about 1200 to about 3500 C in one example, between about 2000 and about 3500 C in another example, and between about 2500 and about 3200 C in yet another example. It is also contemplated herein to produce the hot carrier fluid stream by other known methods, including non-combustion methods. According to one example the carrier fluid stream has a pressure of about 1 atm or higher, greater than about 2 atm in another example, and greater than about 4 atm in another example.

[0029] The hot carrier fluid stream from the combustion zone **25** is passed through a supersonic expander **51** that includes a converging-diverging nozzle **50** to accelerate the flowrate of the carrier fluid to above about mach 1.0 in one example, between about mach 1.0 and mach 4.0 in another example, and between about mach 1.5 and 3.5 in another example. In this regard, the residence time of the fluid in the reactor portion of the supersonic flow reactor is between about 0.5-100 ms in one example, about 1.0-50 ms in another example, and about 1.5-20 ms in another example. The temperature of the carrier fluid stream through the supersonic expander by one example is between about 1000 C and about 3500 C, between about 1200 C and about 2500 C in another example, and between about 1200 C and about 2000 C in another example.

[0030] A feedstock inlet **40** is provided for injecting the methane feed stream into the reactor **5** to mix with the carrier fluid. The feedstock inlet **40** may include one or more injectors **45** for injecting the feedstock into the nozzle **50**, a mixing zone **55**, a diffuser zone **60**, or a reaction zone or chamber **65**. The injector **45** may include a manifold, including for example a plurality of injection ports or nozzles for injecting the feed into the reactor **5**.

[0031] In one approach, the reactor **5** may include a mixing zone **55** for mixing of the carrier fluid and the feed stream. In one approach, as illustrated in FIG. 1, the reactor **5** may have a separate mixing zone, between for example the supersonic expander **51** and the diffuser zone **60**, while in another approach, the mixing zone is integrated into the diffuser section is provided, and mixing may occur in the nozzle **50**, expansion zone **60**, or reaction zone **65** of the reactor **5**. An expansion zone **60** includes a diverging wall **70** to produce a rapid reduction in the velocity of the gases flowing there-through, to convert the kinetic energy of the flowing fluid to thermal energy to further heat the stream to cause pyrolysis of the methane in the feed, which may occur in the expansion section **60** and/or a downstream reaction section **65** of the reactor. The fluid is quickly quenched in a quench zone **72** to stop the pyrolysis reaction from further conversion of the desired acetylene product to other compounds. Spray bars **75** may be used to introduce a quenching fluid, for example water or steam into the quench zone **72**.

[0032] The reactor effluent exits the reactor via outlet **80** and as mentioned above forms a portion of the hydrocarbon stream. The effluent will include a larger concentration of acetylene than the feed stream and a reduced concentration of methane relative to the feed stream. The reactor effluent stream may also be referred to herein as an acetylene stream as it includes an increased concentration of acetylene. The acetylene stream may be an intermediate stream in a process to form another hydrocarbon product or it may be further processed and captured as an acetylene product stream. In one example, the reactor effluent stream has an acetylene concentration prior to the addition of quenching fluid ranging from about 2 mol-% to about 30 mol-%. In another example, the

concentration of acetylene ranges from about 5 mol-% to about 25 mol-% and from about 8 mol-% to about 23 mol-% in another example.

[0033] The reactor vessel **10** includes a reactor shell **11**. It should be noted that the term “reactor shell” refers to the wall or walls forming the reactor vessel, which defines the reactor chamber **15**. The reactor shell **11** will typically be an annular structure defining a generally hollow central reactor chamber **15**. The reactor shell **11** may include a single layer of material, a single composite structure or multiple shells with one or more shells positioned within one or more other shells. The reactor shell **11** also includes various zones, components, and or modules, as described above and further described below for the different zones, components, and or modules of the supersonic reactor **5**. The reactor shell **11** may be formed as a single piece defining all of the various reactor zones and components or it may be modular, with different modules defining the different reactor zones and/or components.

[0034] As mentioned above, by one approach, the supersonic reactor **5** includes a quench zone **72** for effectively cooling the pyrolysis stream traveling therethrough. It should be noted that as used herein, “pyrolysis stream” may include one or all of the carrier stream, the feed stream, and the product effluent stream, before or during pyrolysis thereof.

[0035] In one approach, the quench zone **72** includes a spray quench system **75** for spraying a quench fluid into the quench zone to contact the pyrolysis stream and decrease the temperature thereof. The quench stream may include one or more of several different quench fluids. While a variety of quench fluids may be used in accordance herewith, by one approach, the quench fluid is selected to not interfere with the pyrolysis reaction other than cooling the pyrolysis stream. The quench fluid may also be selected so that it does not introduce a component into the pyrolysis stream which will contaminate a product thereof or cause difficulty in separating the component from a portion of the effluent stream. In this regard, in one example, the quench stream includes a component that is present in the process stream.

[0036] In one approach, the quench fluid includes cold water or steam. It should be noted that “cold” in reference to the quench stream is relative to the temperature of the pyrolysis stream, as the quench stream may still have an otherwise high temperature. In another approach, the quench fluid includes ethylene. In yet another approach, the quench fluid includes oil. It should be recognized, that these fluids will not substantially interfere with the pyrolysis reaction, other than decreasing the temperature to stop the reaction, and either form a desired part of the process stream or can be separated therefrom.

[0037] In another approach, the quench fluid includes chlorine. In this manner, upon introduction of the quench stream, the chlorine will react with acetylene in the pyrolysis stream to produce vinyl chloride, which may be a desired product.

[0038] In one approach, the quench system includes a quench fluid source **200** and at least one inlet **75**, as illustrated in FIG. 3 for introducing the quench stream into the quench zone **72** of the reactor chamber **15** to quench the pyrolysis stream. In one approach, the inlet includes a nozzle. The nozzle may be configured to direct the quench fluid into the quench zone **72** to provide good mixing of the quench fluid with the pyrolysis stream and desired cooling of the pyrolysis stream.

[0039] As mentioned above, it has been identified that the high temperatures and flowrates, as well as other harsh oper-

ating conditions and components present within the reactor chamber **15** may cause melting and/or deterioration of the equipment and components of the quench system. More particularly, temperatures in the quench zone may, in one example, range from about 1200° C. to about 2500° C. In another example, temperatures in the quench zone may range from about 1500 to about 2000°. The temperature of the fluid in the quench zone may be decreased to less than about 800° C. Further, fluid velocity may be reduced in the quench zone, in one example, from about Mach 1.0 to Mach 3.0 to less than about Mach 0.5. Further, components in the pyrolysis stream may cause corrosion, oxidation, or reduction of equipment or components within the quench zone **72**.

[0040] In this regard, the inlet according to one approach is formed to withstand these harsh operating conditions. While other types of inlets may be used, description will be provided for an inlet including a nozzle. In one approach, one or more portions of the nozzle are formed as a casting. Thus, by forming a portion of the reactor shell as a casting, a more isotropic microstructure is provided. The cast portion of the reactor shell may provide corrosion resistance over similar components formed by other methods, such as welding or forming. Forming the portion of the reactor shell from a casting may also provide better and more uniform high temperature creep and failure resistance than forming the shell by other methods

[0041] By one approach, the casting may include a directional casting to provide improved thermal shock resistance and creep resistance at the elevated reaction temperatures and pressures. In one approach, the casting includes a columnar grain structure. In another approach, the casting includes a single crystal structure.

[0042] The casting may be formed from one or more materials as described further below. The cast portion of the reactor may be further treated by various methods known in the art. For example, the nozzle may be coated, as further described herein, heat treated, tempered, carbided, nitride, or treated in other known methods to improve its properties.

[0043] Thus, by forming a portion of the nozzle as a casting, a more isotropic microstructure is provided. The cast portion of the reactor shell may provide corrosion resistance over similar components formed by other methods, such as welding or forming. Forming the portion of the reactor shell from a casting may also provide better and more uniform high temperature creep and failure resistance than forming the shell by other methods.

[0044] By one approach, at least a portion of the nozzle is constructed of a material having a high melting temperature to withstand the high operating temperatures of the quench zone **72**. In one approach, one or more materials forming the portion of the nozzle may have a long low-cycle fatigue life, high yield strength, resistance to creep and stress rupture, oxidation resistance, and compatibility with coolants and fuels. In one example, at least a portion of the nozzle is formed of a material having a melting temperature of between about 800 and about 4000 C, and in another example from about 1200 to about 3500 C, and in yet another approach between about 1800 and about 3200 C. The materials may also exhibit microstructural stability through diverse thermal and mechanical processing procedures, compatibility with bonding processes and good adherence of oxidation resistant coatings. Some preferred materials for forming at least a portion of the nozzle include superalloy alloys and nickel and gamma

Ti aluminides. By one approach, the superalloy is a nickel based superalloy, and by another approach, the superalloy is an iron based superalloy.

[0045] In one approach, the at least portion of the nozzle is formed from a superalloy. In this regard, the nozzle construction may provide excellent mechanical strength and creep resistance at combustion and pyrolysis temperatures occurring within the reactor. In this manner, the nozzle may also restrict melting or failure due to the operating temperature along with the pressures in the quench zone **72**.

[0046] According to another approach, the portion of the nozzle is formed from a material selected from the group consisting of a carbide, a nitride, titanium diboride, a sialon ceramic, zirconia, thoria, a carbon-carbon composite, tungsten, tantalum, molybdenum, chromium, nickel and alloys thereof.

[0047] According to yet another approach, the portion of the nozzle is formed from a material selected from the group consisting of the casting comprises a component selected from the group consisting of duplex stainless steel, super duplex stainless steel, and nickel-based high-temperature low creep superalloy.

[0048] Chromium or nickel may be included to provide good corrosion resistance.

[0049] According to one approach, one or more components of the system may be removed and replaced during operation of the supersonic reactor **5** or during downtime thereof. For example, the quench nozzle may deteriorate more quickly than other components of the reactor, the nozzle may be removable so that it can be replaced with a new nozzle upon deterioration thereof. In one approach, a plurality of supersonic reactors **5** may be provided in parallel or in series with one or more supersonic reactors in operation and one or more supersonic reactors in standby so that if maintenance or replacement of one or more components of the operating supersonic reactor **5** is required, the process may be switched to the standby supersonic reactor to continue operation.

[0050] In one example, the reactor effluent stream after pyrolysis in the supersonic reactor **5** has a reduced methane content relative to the methane feed stream ranging from about 15 mol-% to about 95 mol-%. In another example, the concentration of methane ranges from about 40 mol-% to about 90 mol-% and from about 45 mol-% to about 85 mol-% in another example.

[0051] In one example the yield of acetylene produced from methane in the feed in the supersonic reactor is between about 40% and about 95%. In another example, the yield of acetylene produced from methane in the feed stream is between about 50% and about 90%. Advantageously, this provides a better yield than the estimated 40% yield achieved from previous, more traditional, pyrolysis approaches.

[0052] By one approach, the reactor effluent stream is reacted to form another hydrocarbon compound. In this regard, the reactor effluent portion of the hydrocarbon stream may be passed from the reactor outlet to a downstream hydrocarbon conversion process for further processing of the stream. While it should be understood that the reactor effluent stream may undergo several intermediate process steps, such as, for example, water removal, adsorption, and/or absorption to provide a concentrated acetylene stream, these intermediate steps will not be described in detail herein.

[0053] Referring to FIG. **2**, the reactor effluent stream having a higher concentration of acetylene may be passed to a downstream hydrocarbon conversion zone **100** where the

acetylene may be converted to form another hydrocarbon product. The hydrocarbon conversion zone **100** may include a hydrocarbon conversion reactor **105** for converting the acetylene to another hydrocarbon product. While FIG. 2 illustrates a process flow diagram for converting at least a portion of the acetylene in the effluent stream to ethylene through hydrogenation in hydrogenation reactor **110**, it should be understood that the hydrocarbon conversion zone **100** may include a variety of other hydrocarbon conversion processes instead of or in addition to a hydrogenation reactor **110**, or a combination of hydrocarbon conversion processes. Similarly, unit operations illustrated in FIG. 2 may be modified or removed and are shown for illustrative purposes and not intended to be limiting of the processes and systems described herein. Specifically, it has been identified that several other hydrocarbon conversion processes, other than those disclosed in previous approaches, may be positioned downstream of the supersonic reactor **5**, including processes to convert the acetylene into other hydrocarbons, including, but not limited to: alkenes, alkanes, methane, acrolein, acrylic acid, acrylates, acrylamide, aldehydes, polyacetylides, benzene, toluene, styrene, aniline, cyclohexanone, caprolactam, propylene, butadiene, butyne diol, butandiol, C2-C4 hydrocarbon compounds, ethylene glycol, diesel fuel, diacids, diols, pyrrolidines, and pyrrolidones.

[0054] A contaminant removal zone **120** for removing one or more contaminants from the hydrocarbon or process stream may be located at various positions along the hydrocarbon or process stream depending on the impact of the particular contaminant on the product or process and the reason for the contaminants removal, as described further below. For example, particular contaminants have been identified to interfere with the operation of the supersonic flow reactor **5** and/or to foul components in the supersonic flow reactor **5**. Thus, according to one approach, a contaminant removal zone is positioned upstream of the supersonic flow reactor in order to remove these contaminants from the methane feed stream prior to introducing the stream into the supersonic reactor. Other contaminants have been identified to interfere with a downstream processing step or hydrocarbon conversion process, in which case the contaminant removal zone may be positioned upstream of the supersonic reactor or between the supersonic reactor and the particular downstream processing step at issue. Still other contaminants have been identified that should be removed to meet particular product specifications. Where it is desired to remove multiple contaminants from the hydrocarbon or process stream, various contaminant removal zones may be positioned at different locations along the hydrocarbon or process stream. In still other approaches, a contaminant removal zone may overlap or be integrated with another process within the system, in which case the contaminant may be removed during another portion of the process, including, but not limited to the supersonic reactor **5** or the downstream hydrocarbon conversion zone **100**. This may be accomplished with or without modification to these particular zones, reactors or processes. While the contaminant removal zone **120** illustrated in FIG. 2 is shown positioned downstream of the hydrocarbon conversion reactor **105**, it should be understood that the contaminant removal zone **120** in accordance herewith may be positioned upstream of the supersonic flow reactor **5**, between the supersonic flow reactor **5** and the hydrocarbon conversion zone **100**, or downstream of the hydrocarbon conversion zone **100** as illustrated in FIG. 2 or along other streams within the

process stream, such as, for example, a carrier fluid stream, a fuel stream, an oxygen source stream, or any streams used in the systems and the processes described herein.

[0055] While there have been illustrated and described particular embodiments and aspects, it will be appreciated that numerous changes and modifications will occur to those skilled in the art, and it is intended in the appended claims to cover all those changes and modifications which fall within the true spirit and scope of the present disclosure and appended claims.

What is claimed is:

1. An apparatus for producing acetylene from a feed stream comprising methane comprising:
 - a supersonic reactor for receiving the methane feed stream and heating the methane feed stream to a pyrolysis temperature to produce an effluent;
 - a reactor shell of the supersonic reactor for defining a reactor chamber;
 - a combustion zone of the supersonic reactor for combusting a fuel source to provide a high temperature carrier gas passing through the reactor space at supersonic speeds to mix with the methane feed stream to form a pyrolysis stream and heat and accelerate the methane feed stream to a pyrolysis temperature; and
 - a quench zone for effectively decreasing the temperature of the pyrolysis stream.
2. The apparatus of claim 1, wherein the quench zone comprises a spray quench into the pyrolysis stream comprising cold water.
3. The apparatus of claim 1, wherein the quench zone comprises a spray quench into the pyrolysis stream comprising ethylene.
4. The apparatus of claim 1, wherein the quench zone comprises an oil spray quench into the pyrolysis stream comprising oil.
5. The apparatus of claim 1, wherein the quench zone comprises a spray quench into the pyrolysis stream comprising chlorine to produce vinyl chloride.
6. The apparatus of claim 1, wherein the reactor includes a spray quench nozzle for spraying a quench fluid into the quench zone.
7. The apparatus of claim 6, wherein at least a portion of the nozzle comprises a material having a melting temperature of between about 1000 and about 3500 C.
8. The apparatus of claim 6, wherein at least a portion of the nozzle comprises a superalloy.
9. The apparatus of claim 6, wherein at least a portion of the nozzle comprises a material selected from the group consisting of a carbide, a nitride, titanium diboride, a sialon ceramic, zirconia, thoria, a carbon-carbon composite, tungsten, tantalum, molybdenum, chromium, nickel and alloys thereof.
10. The apparatus of claim 6, wherein at least a portion of the nozzle comprises a material selected from the group consisting of duplex stainless steel, super duplex stainless steel, and nickel-based high-temperature low creep superalloy.
11. A method for producing acetylene comprising:
 - introducing a fuel stream into a combustion zone of a supersonic reactor;
 - combusting the fuel stream to provide a high temperature carrier stream traveling at a supersonic speed;
 - introducing a feed stream portion of a hydrocarbon stream comprising methane into the supersonic reactor;
 - mixing the feed stream portion with the carrier stream to form a pyrolysis stream;

expanding the pyrolysis stream to reduce the speed and increase the temperature of the reactor stream to a pyrolysis temperature to pyrolyze the stream and form an effluent stream; and

contacting the pyrolysis with a quench stream to decrease the temperature thereof.

12. The method of claim **11**, wherein the quench stream comprises cold water.

13. The method of claim **11**, wherein the quench stream comprises ethylene.

14. The method of claim **11**, wherein the quench stream comprises oil.

15. The method of claim **11**, wherein the quench stream comprises chlorine, and producing at least one of dioxin and vinyl chloride.

16. The method of claim **11**, wherein contacting the pyrolysis stream includes spraying a quench stream at the pyrolysis stream.

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