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(54) **CRYOGENICALLY COMPATIBLE ROCKET PROPELLANT**

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(52) **U.S. Cl.**
CPC *C06B 43/00* (2013.01)

(57) **ABSTRACT**

Propellants for rockets, space transportation vehicles, launch vehicles and systems, crew escape vehicles and systems, launch escape towers, and space vehicle systems are disclosed. Some embodiments provide a rocket propellant comprising a mixture of a small chain alkane from 1 to 4 carbons and a small chain alkene from 3 to 4 carbons. The mixture of the small chain alkane and small chain alkene is in a proportion that lowers the melting of the mixture below the melting point of both the small chain alkane and small chain alkene.

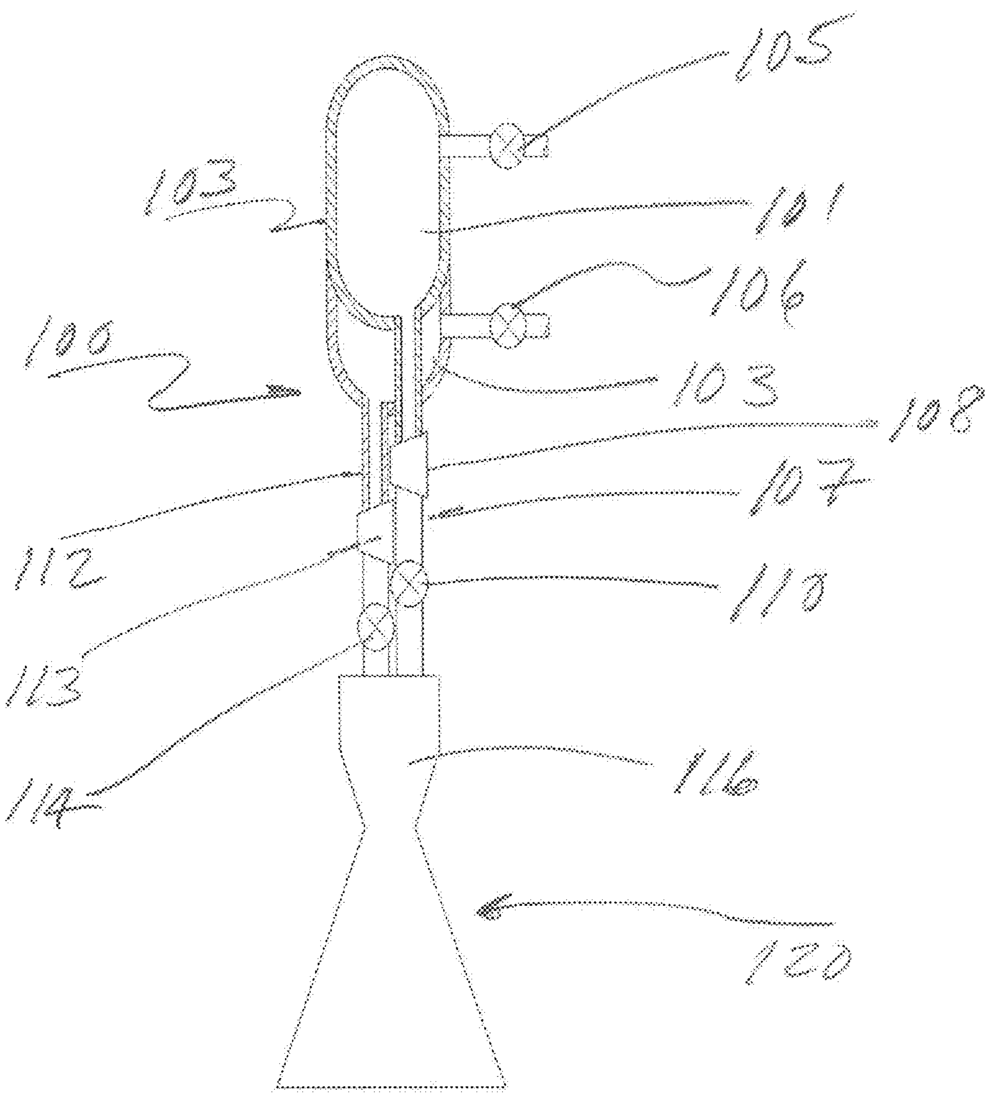


Table 1. Comparison of Melting Point and Boiling Point of Various Fuels to Cooling Sources.

Mix	Melting Point (in Kelvin)	Boiling Point (in Kelvin)	Comments
Oxygen	54 K	90 K	Primary Oxidizer
Nitrogen	63 K	77 K	Working Coolant
Hydrogen	14 K	21 K	Fuel Option
RP-1	200 K	425 K	Fuel Option
Methane	91 K	112 K	Fuel Option
Ethane	90K	184K	Fuel Option
Propane	85 K	230 K	Fuel Option
Butane	135K	272K	Fuel Option
Ethylene	104K	169K	Fuel Option
Propylene	88 K	226 K	Fuel Option

FIG 1

	Specific Impulse (seconds)	Bulk Density (kg/m^3)	Density Impulse (seconds)
RP-1	373.6	1057	394.9
Methane	384.5	992	381.4
Methane-Propene	383.0	1079	413.4
Propane-Propene	380.3	1094	416.0

Calculated at 1000 psi (6.87 MPa) chamber pressure with a nozzle expansion ratio of 100:1

RP-1 @ 273.2 K - 1 atm (STP), Methane @ 111.7 K - 1 atm (NBP)

Methane-Propene @ LN2 NBP (77.3 K), Propane-Propene @ LN2 NBP (77.3 K)

FIG 2

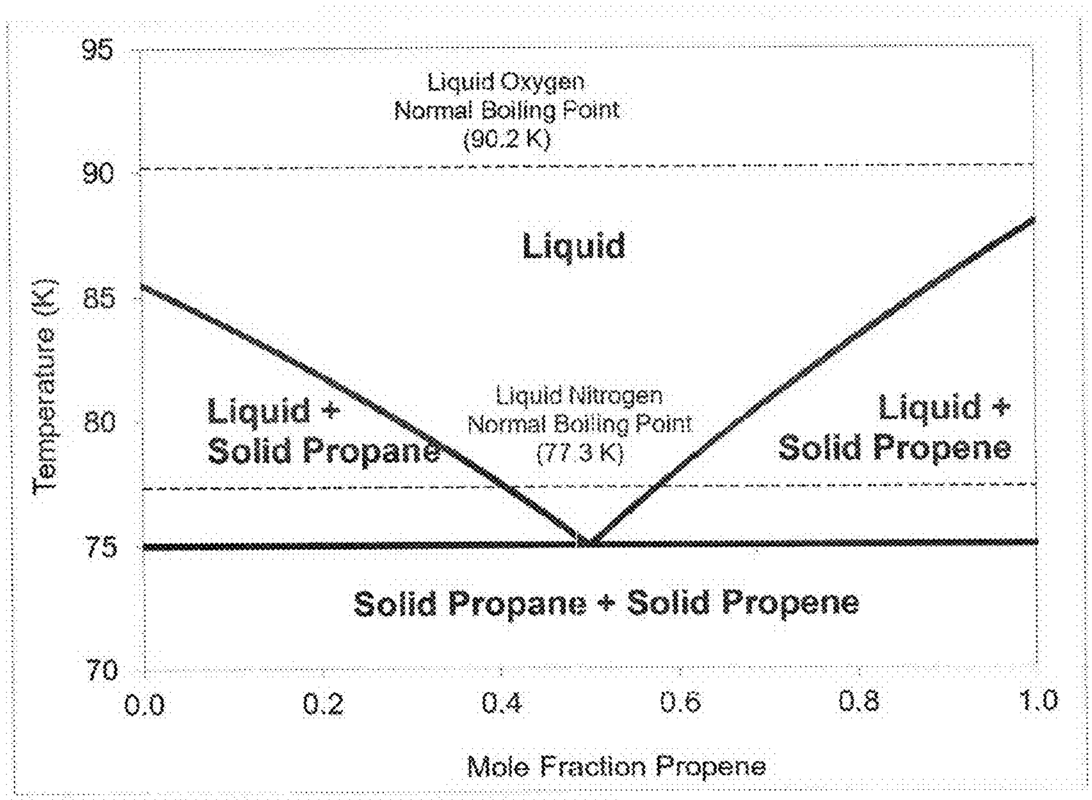

95
90
85
80
75
70
Temperature (K)
Liquid Oxygen
Normal Boiling Point
(90.2 K)
Liquid
Liquid +
Solid Propane
Liquid Nitrogen
Normal Boiling Point
(77.3 K)
Liquid +
Solid Propene
Solid Propane + Solid Propene
0.0
0.2
0.4
0.6
0.8
1.0
Mole Fraction Propene

FIG 3

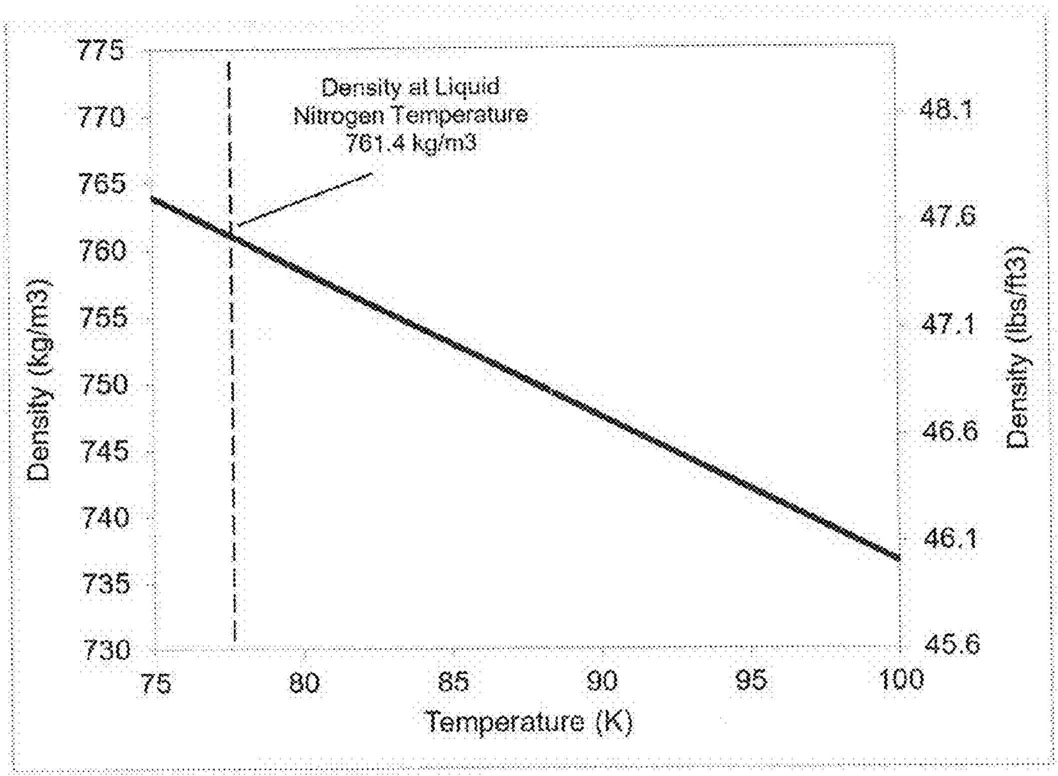

Density at Liquid
Nitrogen Temperature
761.4 kg/m3
775
770
765
760
755
750
745
740
735
730
Density (kg/m3)
48.1
47.6
47.1
46.6
46.1
45.6
Density (lbs/ft3)
75
80
85
90
95
100
Temperature (K)

FIG 4

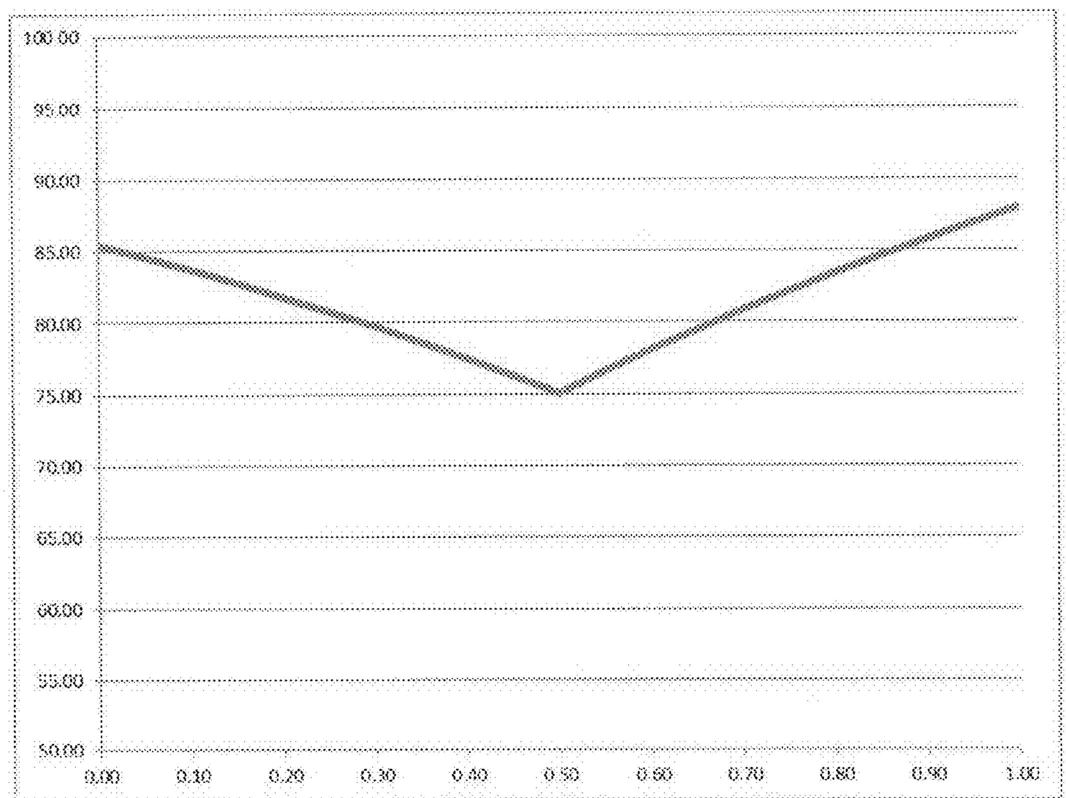

100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

FIG 5

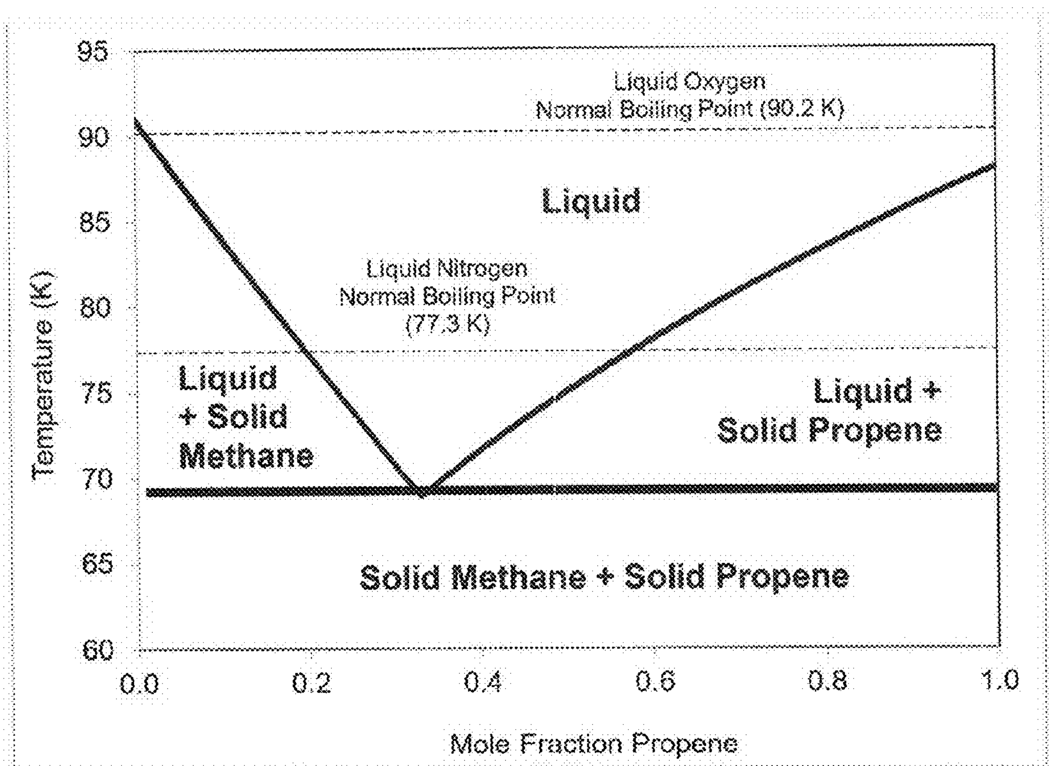

95
90
85
80
75
70
65
60
Temperature (K)
Liquid Oxygen
Normal Boiling Point (90.2 K)
Liquid
Liquid Nitrogen
Normal Boiling Point
(77.3 K)
Liquid
+ Solid
Methane
Liquid +
Solid Propene
Solid Methane + Solid Propene
0.0
0.2
0.4
0.6
0.8
1.0
Mole Fraction Propene

FIG 6

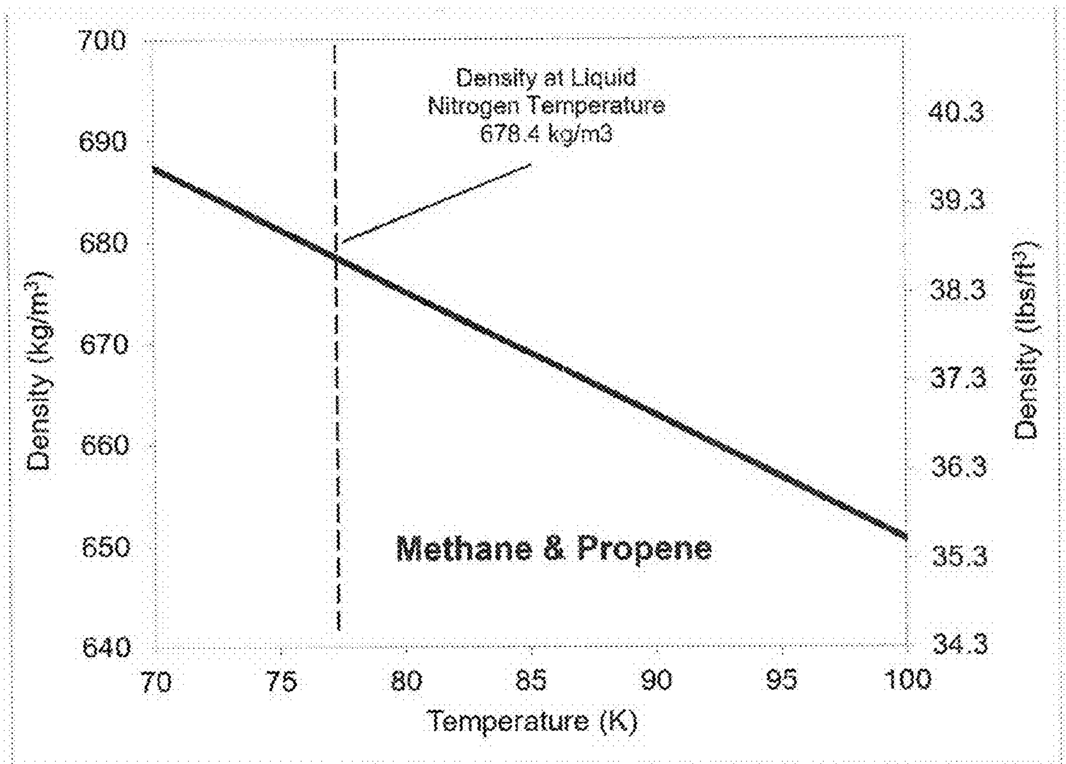
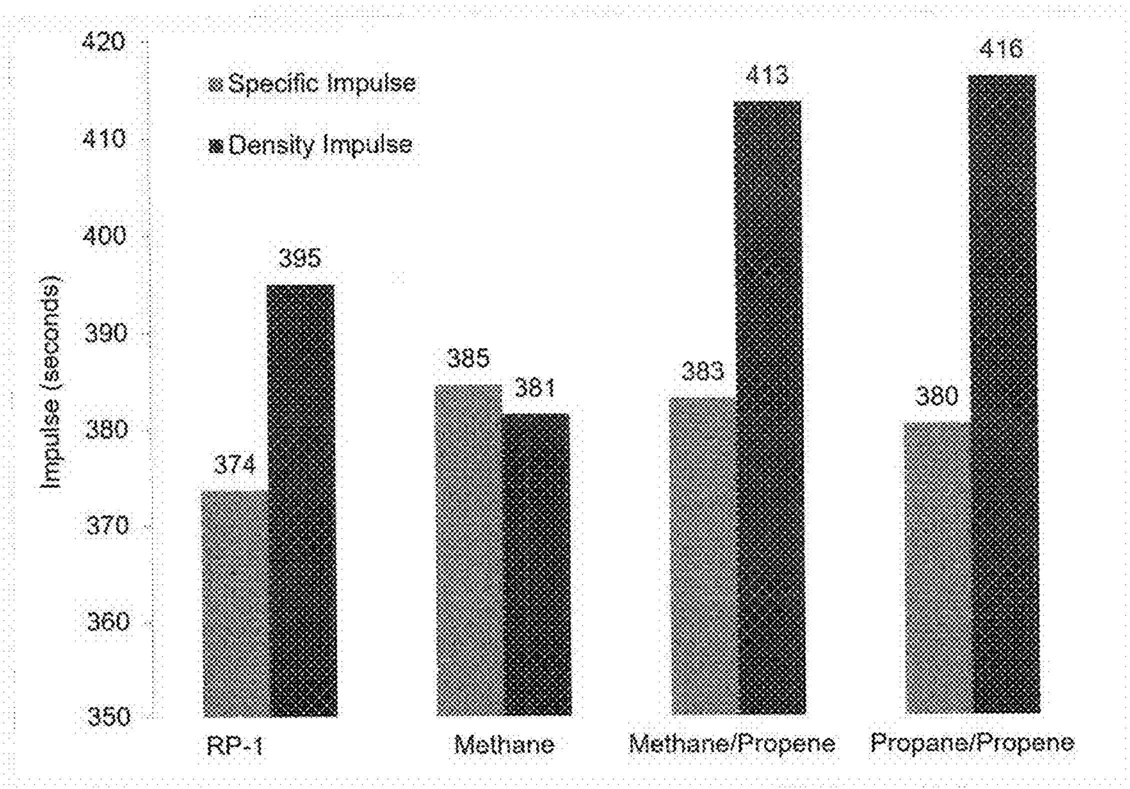

Density at Liquid
Nitrogen Temperature
678.4 kg/m3
Methane & Propene
Density (kg/m^3)
700
690
680
670
660
650
640
Density (lbs/ft^3)
40.3
39.3
38.3
37.3
36.3
35.3
34.3
70
75
80
85
90
95
100
Temperature (K)

FIG 7



Specific Impulse
Density Impulse
Impulse (seconds)
420
410
400
390
380
370
360
350
374
395
385
381
383
413
380
416
RP-1
Methane
Methane/Propene
Propane/Propene

FIG 8

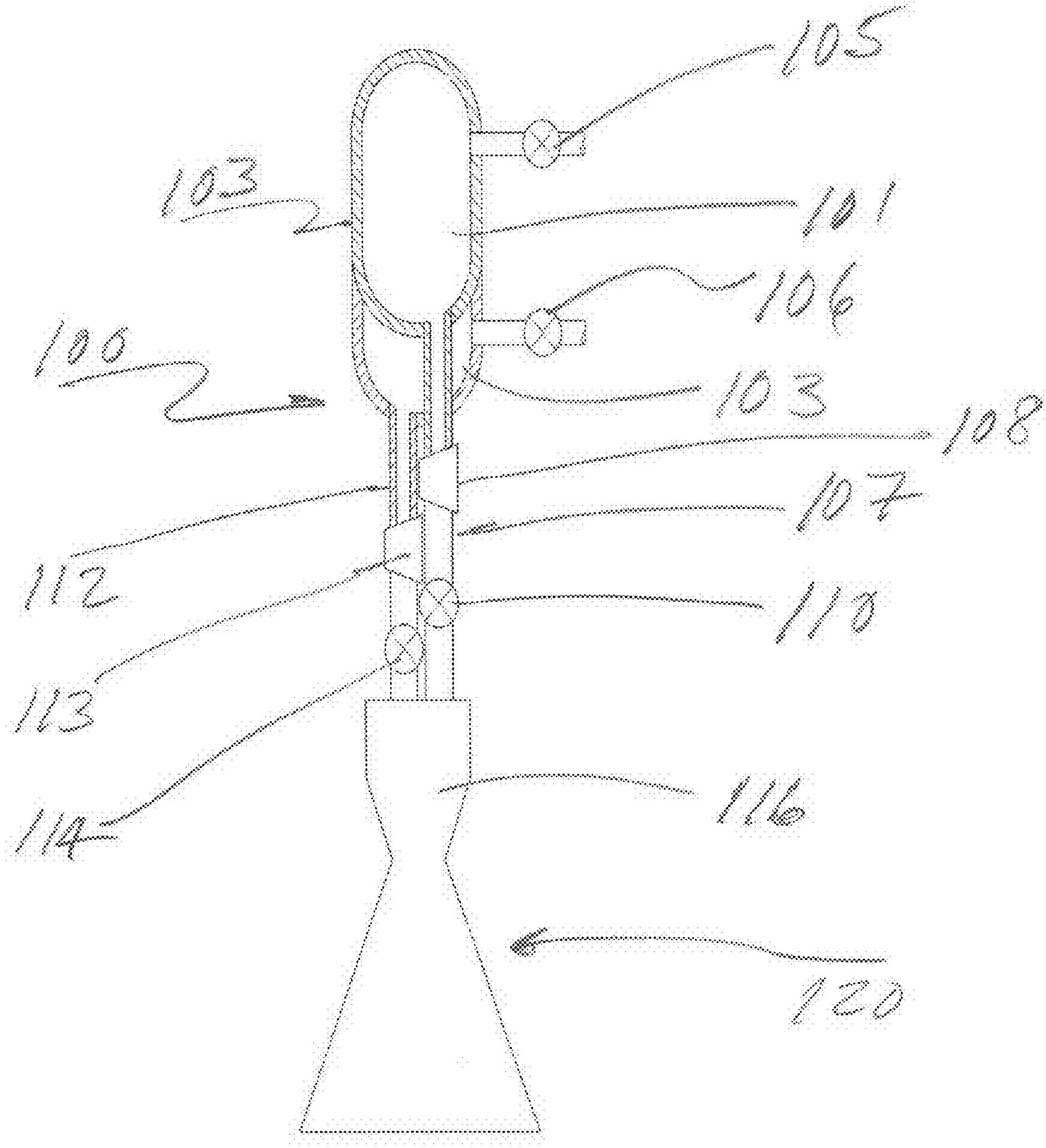


FIG 9

CRYOGENICALLY COMPATIBLE ROCKET PROPELLANT

CROSS-RELATED APPLICATIONS

[0001] This application benefits and claims priority to U.S. Provisional Patent Application Ser. No. 62/222,390, filed Sep. 23, 2015, entitled "Reduced-Temperature Propellant for Rockets and the Like," which is incorporated by reference.

BACKGROUND

[0002] Propellants for rockets, space transportation vehicles, launch vehicles and systems, crew escape vehicles and systems, launch escape towers, and space vehicle systems and devices are known in the art.

[0003] With the rise of the chemical industries of the 19^{th} century, combustion of liquid fuels and oxidizers enabled practical implementation of rocket propulsion systems. Starting with acid/analines and liquid oxygen (LOX)/alcohol and hydrazine/peroxide combinations, the industry rapidly settled on LOX/liquid hydrogen (LH) and LOX/kerosene. While numerous potential combinations, such as LOX/hydrazine, LOX/methane, were studied, kerosene (RP-1) provided the most energetic combination and the greatest experience base. However, thermal incompatibility of kerosene to liquid oxygen continue to require complex engineering solutions.

[0004] The chemical properties of LOX with almost every practical hydrocarbon (HC), such as methane, butane, benzene, gasoline, alcohol, and ether, have been researched as candidates as a rocket propellant, with mixed results. While these fuels are economical, the low densities of small HCs, such as, methane and butane, yield a propellant that is not very efficient. Recent studies have produced a prototype rocket, which uses propylene as a fuel, however, the studies ended without a viable engine.

[0005] In the 1960s, mixtures of methane, ethane, and propane were studied, however, the fuels mixtures required a fluorine-based oxidizer. The density of these mixtures were low, which lowered efficiency, and created problems for storage. These fuel mixtures were abandoned, in favor of RP-1.

[0006] Although RP-1 with LOX is the preferred rocket propellant, there are still drawbacks to this combination. For example, after the burn of RP-1, residue coats the inside of the engine, which needs to be removed to reuse the engine. The residue consists of coke, paraffin, and oils, which are difficult and expensive to remove. If this residue is not completely removed, the engine most likely will fail upon reuse.

[0007] According to the literature, there has not been a completely new liquid propellant used in flight in over 30 years. A new rocket propellant, which is economical, burns clean, and has a high density that is similar to RP-1, and has specific impulse equal to or greater than RP-1, is needed.

SUMMARY

[0008] In some embodiments of the present invention, a mixture of propane and propylene makes an improved rocket fuel by lowering the freezing point and improving the bulk density. In one aspect, the mixture of propane and propylene is a mixture of about 50% propane/about 50% propylene.

[0009] Some embodiments provide a rocket propellant comprising a mixture of a small chain alkane from 1 to 4 carbons and a small chain alkene from 3 to 4 carbons. The mixture of the small chain alkane and small chain alkene is in a proportion that lowers the melting of the mixture below the melting point of both the small chain alkane and small chain alkene.

DRAWINGS

[0010] The present disclosure will become more fully understood from the description and the accompanying drawings, wherein:

[0011] FIG. **1** is a table, which illustrates a comparison of the melting points and the boiling points of various fuels to coolant sources, in accordance to various embodiments;

[0012] FIG. **2** is a table, which illustrates a comparison of various physical properties of various fuels, in accordance with various embodiments;

[0013] FIG. **3** is a phase diagram for a mixture of propane and propene, in accordance with various embodiments;

[0014] FIG. **4** is a graph illustrating the change in density of propane and propene at a mixture 50:50 in mole fraction over a change in temperature, in accordance with various embodiments;

[0015] FIG. **5** is a phase diagram for a mixture of ethane and propene, in accordance with various embodiments;

[0016] FIG. **6** is a phase diagram for a mixture of methane and propene, in accordance with various embodiments;

[0017] FIG. **7** is a graph illustrating the change in density of methane and propene at a mixture 50:50 in mole fraction over a change in temperature, in accordance with various embodiments

[0018] FIG. **8** is a bar graph illustrating the values of specific impulse and density impulse for 4 different propellants; and

[0019] FIG. **9** is a schematic drawing illustrating a cross-section of an exemplary rocket system, in accordance with various embodiments.

[0020] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of any of the exemplary embodiments disclosed herein or any equivalents thereof. It is understood that the drawings are not drawn to scale. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements.

DESCRIPTION

[0021] The following description is merely exemplary in nature and is in no way intended to limit the exemplary embodiments, their application, or uses. It should be understood that steps within a method may be executed in different order without altering the principles of the present disclosure. For example, various embodiments may be described herein in terms of various functional components and processing steps. It should be appreciated that such components and steps may be realized by any number of hardware components configured to perform the specified functions.

[0022] Various embodiments provide compositions, which are propellants for rockets, space transportation vehicles, launch vehicles and systems, crew escape vehicles and systems, launch escape towers, and space vehicle systems and devices. The compositions can be a reduced-temperature propellant for improving performance of a rocket stage, a rocket, a space vehicle, and the like. Some embodiments provide a system, which can be employed as a rocket engine.

[0023] Some embodiments provide a rocket propellant mixture comprising a small chain alkane mixed with a small chain alkene. The small chain alkane can comprise from 1 to 4 carbons and the small chain alkene can comprise from 3 to 4 carbons. The mixture of the small chain alkane and small chain alkene is in a proportion that lowers the melting of the mixture below the melting point of both the small chain alkane and small chain alkene. In other words, the mixture of the small chain alkane and small chain alkene is in a proportion, which allows the mixture to be a liquid at a temperature that both the small chain alkane and the small chain alkene are solids. In some aspects, the mixture of the small chain alkane and small chain alkene is in a proportion that is about 50:50 in mole fraction for each component. The rocket propellant mixture can be combined with liquid oxygen (LOX) in a rocket engine.

[0024] In one embodiment, the rocket propellant mixture comprises propane and propene (propylene). In one example, the rocket propellant mixture consists of propane and propene at a mole fraction 50 for each component. However, the range of the fraction for each component is +/−5. For example, the mixture can consist of propane in a mole fraction of 45 and propene in a mole fraction of 55 or the mixture can consist of propane in a mole fraction of 55 and propene in a mole fraction of 45 or any combination in between these examples.

[0025] In other embodiments, the rocket propellant mixture comprises ethane and propene. In one example, the rocket propellant mixture consists of ethane and propene at a mole fraction 50 for each component. However, the range of the fraction for each component is +/−5.

[0026] In still other embodiments, the rocket propellant mixture comprises methane and propene. In one example, the rocket propellant mixture consists of methane and propene at a mole fraction 50 for each component. However, the range of the fraction for each component is +/−5.

[0027] The rocket propellant mixture, as described herein, can be cryogenically chilled to the boiling point of liquid nitrogen (LN) and still remain in a liquid state. The rocket propellant mixture can remain in a liquid state while in thermal communication with a cryogenic source.

[0028] Turning to FIG. **1**, Table 1 is comparison of the melting points and boiling points of various fuels to cooling sources. Although most of these fuels can be combined with an oxidizer other than LOX, the focus of this discussion will only on LOX as the oxidizer. As illustrated in Table 1, available coolants are LOX and LN, which can be used to cool the LOX. In some rocket designs, LOX may not be cooled by LN but rather LOX is vented to atmosphere and topped off as the level drops. In these designs only LOX is available as a coolant.

[0029] As a note to Table 1, RP-1 is Rocket Propellant 1 or Refined Petroleum 1, as is well known those skilled in the art. RP-1 is a refined form of kerosene, which is cheaper than liquid hydrogen (LH) and is stable at room temperature. Although RP-1 has lower specific impulse ("Isp") than LH, RP-1 is far higher density than LH, therefore it is far more powerful than LH by volume.

[0030] Other than LH, all of the listed fuels are solids at the boiling point (77K) of LN. Since the rocket propellant needs to flow from a tank to the combustion chamber and mix with the LOX, a solid fuel cannot to used. In addition to LH, propane, propene, ethane and maybe even methane are liquids at the boiling point (90K) of LOX, while all of the other fuels are solid at the boiling point of LOX. Please note that the density of LH is far less than the density of all of the other fuels listed in Table 1.

[0031] From the comparison in Table 1, none of the hydrocarbon (HC) based fuels can be used as a rocket propellant while in thermal communication with LN. Of the HC fuels listed, most of the small chain HC fuels can be used can be used as a rocket propellant while in thermal communication with LOX.

[0032] In very unexpected results, the inventors discovered that certain small chain alkane from 1 to 4 carbons and certain small chain alkene from 3 to 4 carbons can be mixed in certain proportions that lowers the melting of the mixture below the melting point of both the small chain alkane and small chain alkene. These mixtures are cryogenically compatible with various cryogenic coolants and have increased density near the melting point of the mixture. The inventors determined that these mixtures can be used for rocket propellants.

[0033] Now moving to FIG. **2**, Table 2 is a performance comparison of various fuels. In very unexpected results, the inventors discovered that a mixture of methane and propene has a eutectic point at certain mixtures, which below the boiling point of LN. This mixture of methane and propene has an increased density and has physical properties that make it superior to RP-1 as a rocket propellant, as shown in FIG. **2**.

[0034] In very unexpected results, the inventors discovered that a mixture of propene and propene has a eutectic point at certain mixtures, which below the boiling point of LN. This mixture of propane and propene has an increased density and has physical properties that make it superior to RP-1 as a rocket propellant, as shown in FIG. **2**.

[0035] A brief review of the table above shows that LOX is thermally compatible with both propane and propylene (propene) and that nominally LN is thermally incompatible with methane, propane and propylene. It is not commonly appreciated that the density of propane and propylene at the melting point makes them excellent rocket fuels, because most property tables for propane and propylene are calibrated to the normal boiling point (NBP) of propane and propylene. Most practicing engineers look at the density of propane as 0.49 g/cc at the NBP, not the effective density of propane at the melting point of 1.01 g/cc, and fail to appreciate the dramatic density rise of propane as it is subcooled towards the melting point. The even better density of a propane mix such as about 50%/50% blend of propane/propylene (Pro/Poly 50) subcooled to near the NBP of LN where it increases towards 1.06 g/cc, which grants a 5% density impulse gain over subcooled propane.

[0036] A eutectic (minimum freezing point) mixture of propane and propylene provides over 372 seconds of theoretical specific impulse, while having a freezing point margin of 10 K (80 K) below the normal atmospheric boiling point of LOX. This fuel combination then will provide a high specific impulse, and hence a reasonable structural mass fraction (SMF) and propellant mass fraction (PMF), while keeping tank design simple, tank weights low, and overall stage manufacturing costs reasonable.

[0037] In one aspect of the present invention, mixtures of propane/propylene, preferably about a 50%/50% mixture (Pro/Poly 50), exhibit strong reduction in melting point, while a eutectic mixture should exhibit a melting point (about 75 Kelvin (K)) compatible with exposure to liquid nitrogen (LN). Mixtures of propane/propylene can be cooled with LN, LOX, liquid helium or by active mechanical coolers or other methods known to one of ordinary skill in the art.

[0038] An enhanced Pro/Poly mix can be mixed at any ratio of propane/propylene which results in a reduced melting point down to the eutectic point. The eutectic point is a mixture of approximately 50% propane/50% propylene +/−5%, and is below the boiling point for LN and calculations indicates should have a melting point of about 75 K.

[0039] A colder, denser propellant provides a higher density impulse than the same propellant at the normal boiling point (NBP). A liquid pro/poly 50 mixes as liquid phase with LOX providing complete blending before ignition giving a potential for about 100% combustion efficiency. A denser propellant reduces pump power requirements to the pump for the equivalent mass flow.

[0040] An increase of density impulse increases the performance of a rocket stage, thus lowering the temperatures and freezing points of propellants results in higher performance even above the engineering improvements engendered by thermal compatability. Pro/Poly 50 will exhibit a bulk density of about 1.06 G/cc, and, at about 77 K, LOX increases in density to about 1.21 g/cc

[0041] Some embodiments provide mixtures of propane/propylene and to lower the melting point into the working ranges for LN. This ultimately approaches the eutectic point wherein the freezing (melting) point of a propane/propylene mixture can be lowered and the viscosity engineered to meet the requirements of passage through fine cooling passages and through a high speed turbopump.

[0042] FIG. **3** is a phase diagram for a mixture of propane and propene, which has temperature in K on the y-axis and the increasing mole fraction of propene on the x-axis. This phase diagram illustrates that any mixture of propane and propene has a lower melting point (in degrees K) than the melting point for either pure propane or pure propene. The point at which a mixture has lowest melting (eutectic point) is indicated on the phase diagram. In addition, the boiling points of LN and LOX have been added to this phase diagram. From an analysis of the phase diagram, the eutectic point is at a mole fraction of 50% propane and a mole fraction of 50% propene, which has a melting point of 75.0K. As illustrated on the phase diagram, the eutectic point is below the boiling point of LN and this mixture will remain in a liquid state while in thermal communication with LN. As indicated on the phase diagram, other mixtures of propane and propene have a melting point below LN.

[0043] Based on the data that generated the phase diagram, at a mole fraction of 45% propane and a mole fraction of 55% propene, the melting point of this mixture is 76.27K, which is below the melting point of LN (77.3K). Furthermore, at a mole fraction of 55% propane and a mole fraction of 45% propene, the melting point of this mixture is 76.27K, which is also below the melting point of LN (77.3K). These mixtures provide the termini of a range of mixtures of propane and propene that can be used a cryogenically LN compatible rocket propellant.

[0044] However, at a mole fraction of 60% propane and a mole fraction of 40% propene, the melting point of this mixture is 77.48 K, which is slightly above the melting point of LN (77.3K). at a mole fraction of 40% propane and a mole fraction of 60% propene, the melting point of this mixture is 77.48 K, which is slightly above the melting point of LN (77.3K). Since the LN, while in thermal communication with these mixtures, will not chill the mixtures down to the exact boiling point of LN, these mixtures provide the termini for an alternative range of mixtures of propane and propene that can be used a cryogenically LN compatible rocket propellant. Still further, the combinations of mole fraction of 65% and 35% of each component have a melting point of 78.64K, which is slightly higher than LN (77.3K). As discussed above, these mixtures provide the termini for a second alternative range of mixtures of propane and propene that can be used a cryogenically LN compatible rocket propellant. The combinations of mole fraction of 70% and 30% of each component have a melting point of 79.74K, which is also slightly higher than LN (77.3K). If efficiency of the thermal communication of the LN is low, these mixtures provide the termini for a third alternative range of mixtures of propane and propene that can be used a cryogenically LN compatible rocket propellant.

[0045] Of course adding pressure to any of these mixtures, can further reduce the melting point of the mixture. Although high pressure in a tank is not the best configuration in a rocket engine while in flight. The tank can be pressurized while the rocket is still on the ground during prelaunch, which can further lower the melting point of any of these mixtures. Moving back to FIG. **3**, since both propane and propene have melting points below the boiling point of LOX, as illustrated in Table 1 of FIG. **1**, any mixture of propane and propene will be in a liquid state at the boiling point of LOX. If LOX is used as a coolant, any of pure propane, pure propene, or any mixture thereof, can be used a cryogenically LOX compatible rocket propellant.

[0046] Flipping to FIG. **4**, a graph illustrates the change in density of propane and propene at a mixture 50:50 in mole fraction over a change in temperature. The graph has density in the units of kg/m3 on the left hand y-axis and density in the units of lbs/ft3 on the right hand y-axis. A temperature range from 75K to 100K is on the x-axis. From this data, the density of the mixture increases as temperature decreases. At the boiling point of LN, the density of the mixture is 761.4 kg/m3. The cryogenic cooling of the mixture to below the boiling point of LN increases the fuel density, which increases the performance of this fuel mixture as a rocket propellant. The fuel density of this mixture is greater than RP-1

[0047] FIG. **5** is a phase diagram for a mixture of ethane and propene, which has temperature in K on the y-axis and the increasing mole fraction of propene on the x-axis. This phase diagram illustrates that any mixture of ethane and propene has a lower melting point (in degrees K) than the melting point for either pure ethane or pure propene. The eutectic point, as well as, boiling points of LN and LOX are included in this phase diagram. From an analysis of the phase diagram, the eutectic point is at a mole fraction of 50% ethane and a mole fraction of 50% propene, which has a melting point of 75.2K.

[0048] As discussed above, other mixture of ethane and propane are in a liquid state at the boiling point of LN. For example, the combinations of mole fraction of 55% and 45%

of each component have a melting point of 76.27, which is below than LN (77.3K). These mixtures provide the termini of a range of mixtures of ethane and propene that can be used a cryogenically LN compatible rocket propellant. In another example, the combinations of mole fraction of 60% and 40% of each component have a melting point of 77.48K, which is slightly higher than LN (77.3K). As discussed above, these mixtures provide the termini for an alternative range of mixtures of methane and propene that can be used a cryogenically compatible rocket propellant. In still another example, the combinations of mole fraction of 65% and 35% of each component have a melting point of 78.64K, which is slightly higher than LN (77.3K). As discussed above, these mixtures provide the termini for a second alternative range of mixtures of propane and propene that can be used a cryogenically LN compatible rocket propellant.

[0049] The mixture of ethane and propene have a larger disparity in the amount of mole fraction for each component. Factors that can contribute to these mixtures being useable, are poor efficiency of thermal communication between the mixture and the LN and/or pressurization of the fuel tank. Of course there are other factors, which could contribute, which are known to those skilled in the art. Since the both ethane and propene are liquid at the boiling point of LOX, if LOX is used as a coolant, any of pure propane, pure propene, or any mixture thereof, can be used a cryogenically LOX compatible rocket propellant.

[0050] FIG. **6** is a phase diagram for a mixture of methane and propene, which has temperature in K on the y-axis and the increasing mole fraction of propene on the x-axis. This phase diagram illustrates that any mixture of methane and propene has a lower melting point (in degrees K) than the melting point for either pure methane or pure propene. The eutectic point, as well as, boiling points of LN and LOX are included in this phase diagram. From an analysis of the phase diagram, the eutectic point is at a mole fraction of 67% methane and a mole fraction of 33% propene, which has a melting point of 68.92K.

[0051] As discussed above, other mixture of methane and propane are in a liquid state at the boiling point of LN. For example, the mixture of mole fraction of 25% of propene and of 75% methane has a melting point of 77.14K, which is below than LN (77.3K). The mixture of mole fraction of 55% of propene and of 45% methane has a melting point of 76.57K, which is below than LN (77.3K). These mixtures provide the termini of a range of mixtures of methane and propene that can be used a cryogenically compatible rocket propellant. In another example, the mixture of mole fraction of 60% of propene and of 40% methane has a melting point of 78.0K, which is slightly higher than LN (77.3K). As discussed above, these mixtures provide the termini for an alternative range of mixtures of methane and propene that can be used a cryogenically LN compatible rocket propellant. In still another example, the mixture of mole fraction of 15% of propene and of 85% methane has a melting point of 80.47K, which is slightly above LN (77.3K). As discussed above, these mixtures provide the termini for a second alternative range of mixtures of propane and propene that can be used a cryogenically LN compatible rocket propellant.

[0052] The mixture of methane and propene have a larger disparity in the amount of mole fraction for each component. Many factors that can contribute to these mixtures being useable, as discussed above Since the propene and maybe methane are liquid at the boiling point of LOX, if LOX is used as a coolant, any of pure propene, or any mixture methane and propene, can be used a cryogenically LOX compatible rocket propellant.

[0053] Flipping to FIG. **7**, a graph illustrates the change in density of methane and propene at a mixture 50:50 in mole fraction over a change in temperature. The graph has density in the units of kg/m3 on the left hand y-axis and density in the units of lbs/ft3 on the right hand y-axis. A temperature range from 75K to 100K is on the x-axis. From this data, the density of the mixture increases as temperature decreases. At the boiling point of LN, the density of the mixture is 678.4 kg/m3. The cryogenic cooling of the mixture to below the boiling point of LN increases the fuel density, which increases the performance of this fuel mixture as a rocket propellant. The fuel density of this mixture is greater than RP-1

[0054] FIG. **8** is a graph comparing specific example of fuels, which has Impulse in seconds on the y-axis and the different fuels along the x-axis. In this graph, the specific impulse (Isp) and the density impulse for 4 different fuels are indicated by both bars and the actual number value (in lb/ft3) at the top of the bar. Since RP-1 is the most used rocket propellant, it is on the graph as the current standard. The other fuels on this graph are methane; a mixture of methane and propene at a 50:50 mole ratio, and a mixture of propane and propene at a 50:50 mole ratio (Pro/Poly 50). The calculations that were used to generate this graph used 1000 psi of chamber pressure, and a nozzle expansion ratio of 100:1.

[0055] From analysis of the graph, the Isp for RP-1 is the lowest of the 4 fuels. The Isp of the other 3 fuels is very similar ranging from 380 to 385. Moreover, the density impulse for RP-1 is the lowest of the 4 fuels. The density impulse of the fuels increases on each fuel moving from left to right. There is a significant increase of over 5% of the density impulse of the Pro/Poly 50 over the RP-1. According to the data on the graph, both of the small chain alkane/small chain alkene mixtures are superior to RP-1.

[0056] Finally, in FIG. **9**, schematic drawing illustrates a cross-section of an exemplary rocket engine system. Rocket engine **100** comprises at propellant tank assembly **103**. A propellant mixture of a small chain alkane from 1 to 4 carbons and a small chain alkene from 3 to 4 carbons (as described herein) is stored in fuel tank **101**, which is communication with fuel source or vent via valve **105**. The LOX is stored in oxidizer tank **103**, which is in communication with LOX source or vent via valve **106**. The propellant tank assembly **103** can be cool with LN. An oxidizer pump **113** moves LOX through oxidizer line **112** and entry into the combustion chamber **116** is controlled by valve **114**. A propellant pump **107** moves propellant mixture through propellant line **107** and entry into the combustion chamber **116** is controlled by valve **110**. The oxidizer and propellant mixture are ignited in the combustion chamber **116** and the thrust is directed through nozzle **120**.

[0057] Some embodiments provide A reduced-temperature propellant mixture for improving performance of a rocket stage, rockets, and the like, said reduced temperature propellant mixture comprising: propane; and propylene, wherein said propylene and said propane are placed in thermal communication in a rocket stage for reduced cost and a smaller rocket stage.

[0058] In some aspects, the reduced-temperature propellant mixture is a mixture of about 50% propane/50% propylene that exhibits a melting point below that of a melting point of pure propane or pure propene and is compatible with a liquid oxidizer. In some aspects, the reduced-temperature propellant mixture is any mixture of propylene and propane for freezing point supression. In some configurations, the reduced-temperature propellant mixture is cooled with liquid nitrogen to between 75 Kelvin and 88 Kelvin to improve performance.

[0059] Some embodiments provide reduced-temperature propellant mixture for improving performance of a rocket stage, rockets, and the like, said reduced-temperature propellant mixture comprising: propane; propylene; and liquid oxidizer, wherein a mixture of said propane and said propylene is maintained in thermal communication with said liquid oxidizer for the purposes of improving a rocket stage.

[0060] The mixture of said propane and said propylene is a mixture of about 50% propane/50% propylene, and wherein said mixture of about 50% propane/50% propylene and said liquid oxidizer are cooled below a normal boiling point to improve performance. A eutectic mixture of said propane and polypropylene is cooled to the melting point is the best choice of a propane/propylene fuel combusted with said liquid oxygen subcooled to that same temperature is the superior operating combination for a rocket propellant.

[0061] As used herein, the phrase "at least one of A, B, and C" can be construed to mean a logical (A or B or C), using a non-exclusive logical "or," however, can be contrasted to mean (A, B, and C), in addition, can be construed to mean (A and B) or (A and C) or (B and C). As used herein, the phrase "A, B and/or C" should be construed to mean (A, B, and C) or alternatively (A or B or C), using a non-exclusive logical "or."

[0062] The present invention has been described above with reference to various exemplary embodiments and examples, which are not intended to be limiting in describing the full scope of systems and methods of this invention. However, those skilled in the art will recognize that equivalent changes, modifications and variations of the embodiments, materials, systems, and methods may be made within the scope of the present invention, with substantially similar results, and are intended to be included within the scope of the present invention, as set forth in the following claims.

1. A reduced-temperature propellant mixture for improving performance of a rocket stage, rockets, and the like, said reduced-temperature propellant mixture comprising:

propane; and

propylene, wherein said propylene and said propane are placed in thermal communication in a rocket stage for reduced cost and a smaller rocket stage.

2. The reduced-temperature propellant mixture according to claim **1**, wherein said reduced-temperature propellant mixture is a mixture of about 50% propane/50% propylene that exhibits a melting point below that of a melting point of pure propane or pure propylene and compatible with a liquid oxidizer.

3. The reduced-temperature propellant mixture according to claim **2**, wherein said reduced-temperature propellant mixture is any mixture of propylene and propane for freezing point supression.

4. The reduced-temperature propellant mixture according to claim **1**, wherein said reduced-temperature propellant mixture is cooled with liquid nitrogen to between 75 Kelvin and 88 Kelvin to improve performance.

5. A reduced-temperature propellant mixture for improving performance of a rocket stage, rockets, and the like, said reduced-temperature propellant mixture comprising:

propane;

propylene; and

liquid oxidizer, wherein a mixture of said propane and said propylene is maintained in thermal communication with said liquid oxidizer for the purposes of improving a rocket stage.

6. The reduced-temperature propellant mixture according to claim **5**, wherein a mixture of said propane and said propylene is a mixture of about 50% propane/50% propylene, and wherein said mixture of about 50% propane/50% propylene and said liquid oxidizer are cooled below a normal boiling point to improve performance.

7. The reduced-temperature propellant mixture according to claim **5**, wherein a eutectic mixture of said propane and polypropylene is cooled to the melting point is the best choice of a propane/propylene fuel combusted with said liquid oxygen subcooled to that same temperature is the superior operating combination for a rocket propellant.

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