

MARINE FUEL COMPOSITIONS

FIELD

[0001] This disclosure relates to residual marine fuels containing a blend of at least one residual fraction and at least one fraction including a fatty acid alkyl ester.

BACKGROUND

[0002] Due to recent changes by the International Maritime Organization (IMO) in January 2020, marine fuels are now required to have no more than 0.5 wt% sulfur in order to reduce sulfur oxide emissions. This is a substantial reduction from the prior sulfur limit of 3.5 wt%. In some coastal areas, known as Emission Control Areas (ECA), the sulfur limit is 0.1% (m/m). Going forward, still further low carbon fuel solutions are likely to be needed to meet the IMO 2050 target to reduce marine carbon emissions by 50% from their 2008 levels.

[0003] Typical marine fuels have sulfur content above the new regulatory limits because sulfur contaminants are concentrated in the heavy fractions of crude oil (“residue”) used for marine fuel blending. Typical solutions for reducing sulfur in marine fuels include desulfurization and dilution of high sulfur residue with a low-sulfur blend component, referred to as a “flux,” which is often a distillate. Desulfurization is expensive and carbon-intensive because it requires substantial energy and hydrogen. Dilution is commonly used, but it can destabilize residual marine fuel and promote sediment and sludge formation. Residue contains asphaltenes that are typically kept in solution by a high concentration of aromatic molecules in the fuel. However, the distillate fuels used as flux are generally much less aromatic than residue, and dilution of a residue with a typical distillate flux can cause the asphaltenes to precipitate.

[0004] A Concawe report titled “Study to evaluate test methods to assess the stability and compatibility of marine fuels in view of the IMO MARPOL Annex VI Regulation 14.1.3 for 2020 Sulphur requirements” was issued in November, 2019.

[0005] What is needed are improved fuel oil compositions, and methods for forming such fuel oil compositions, that can allow low sulfur fuel targets to be achieved while reducing or minimizing sediment formation, sludge formation, and/or other issues related to incompatibility of fuel oil compositions. Preferably, the fuel oil compositions can also assist with reducing overall marine carbon emissions.

SUMMARY

[0006] In various aspects, a fuel or fuel blending composition is provided. The fuel or fuel blending composition can include 20 vol% or more of a resid-containing fraction and 5 vol% to 80 vol% of one or more fatty acid alkyl esters. The one or more fatty acid alkyl esters can have a BNCI of 50 or less and a S_{BN} of 55 or more. Methods for forming such a fuel or fuel blending

composition are also provided. Optionally, the fuel or fuel blending composition can further include a secondary flux. The secondary flux can correspond to additional renewable flux or conventional distillate flux. Optionally, the amount of renewable flux can correspond to 25 vol% or more of the fuel or fuel blending composition. Optionally, the resulting fuel or fuel blending composition can have a BMCI – TE difference value of 15 or less.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 shows compositional information and properties for various fatty acid methyl ester fractions and resid-containing fractions.

[0008] FIG. 2 shows properties for blends formed from the fractions shown in FIG. 1.

[0009] FIG. 3 shows properties for blends formed from the fractions shown in FIG. 1.

[0010] FIG. 4 shows modeled properties for blends formed using a combination of fatty acid alkyl ester and conventional distillate flux.

DETAILED DESCRIPTION

[0011] In various aspects, it has been discovered that fatty acid alkyl esters can provide unexpected benefits when used as a blend component for forming residual marine fuels and/or fuel blending components. Although fatty acid alkyl esters have relatively low Bureau of Mines Correlation Index (BMCI) values, it has been discovered that fatty acid alkyl esters have unexpectedly high compatibility with residual fractions. As a result, addition of fatty acid alkyl ester to a vacuum resid or an atmospheric resid fraction can result in reduced or minimized sediment and/or sludge formation relative to addition of a conventional distillate flux fraction. This can be beneficial for forming marine residual fuel oils, where distillate flux is typically used to improve the properties of a resid fraction by a sufficient amount to satisfy one or more values in a marine fuel oil specification. The unexpected reduction in sediment and/or sludge formation can allow fatty acid alkyl esters to be used as a flux for challenged resid fractions that otherwise would be prone to sediment formation when blended with a conventional distillate flux.

[0012] Conventionally, many types of marine residual fuels (and/or fuel blending components) are made by blending an optionally hydrotreated vacuum resid fraction with a hydrotreated distillate flux. Part of the benefit of blending the vacuum resid fraction with the hydrotreated distillate flux is that the sulfur level of the resulting blend is reduced relative to the sulfur content of the optionally hydrotreated vacuum resid fraction. Other benefits can include reducing the kinematic viscosity and/or density of the blend relative to the vacuum resid fraction, so that the resulting blend can satisfy the specifications for one or more types of residual fuel oil.

[0013] Although distillate flux is effective for reducing sulfur, kinematic viscosity, and density of a vacuum resid fraction, blending a distillate flux with vacuum resid can also pose

challenges with regard to maintaining solubility of various types of aromatic species within a resid fraction. If too much distillate flux is added to a resid fraction, asphaltenes and/or other multi-ring aromatic species within the resid fraction can potentially phase separate, resulting in sediment and/or sludge formation.

[0014] The Bureau of Mines Correlation Index (BMCI) is commonly used to characterize fractions corresponding to and/or including an atmospheric resid fraction or a vacuum fraction. This is in part due to the relative ease with which BMCI values can be determined. Based in part on the availability of BMCI values, a common way of evaluating the compatibility of fractions for blending is based on the difference between BMCI values and the toluene equivalence (TE) values of the fractions. Generally, a sample that has a BMCI value that is greater than the TE value by 15 or more indicates that the sample has sufficient solvation power to maintain asphaltenes and/or other multi-core aromatic compounds in solution. By contrast, a difference between BMCI and TE (also referred to as a BMCI – TE value) of 15 or less indicates that sediment is likely to form (and/or a cleanliness rating of 3 or more will occur during a spot test according to ASTM D4740) due to precipitation of asphaltenes and/or other multi-core aromatics. However, in some instances, a BMCI – TE value of 12 or more can still correspond to sample with sufficient solvation power to maintain compatibility. This would correspond to a BMCI – TE value of 12 or less being an indicator of likely precipitation of asphaltenes. Generally, a BMCI – TE value of 10 or less for a sample can indicate that sediment formation will occur and/or a spot rating of 3 or more will occur during a spot test according to ASTM D4740.

[0015] When two fractions are blended, the BMCI value of the resulting blend is typically similar to the weighted average of the BMCI values of the blend components. However, when at least 10 vol% of a resid fraction is included in a blend, the TE value of the blend is typically similar to the TE value of the resid fraction. The TE value is an indicator of the types of multi-core aromatic compounds present within a fraction. For the multi-core aromatics that lead to sediment or sludge formation, however, simply reducing the concentration to avoid sediment formation does not become effective until the concentration has been reduced to a de minimis level. Thus, the presence of even a few percent of a resid fraction in a blend can lead to incompatibility issues if the aromatic solvation power of the blend is too low.

[0016] It has been discovered that fatty acid alkyl esters have an unexpectedly high compatibility for blending with resid fractions. Fatty acid alkyl esters can typically have BMCI values of around 40 or less. This is similar to the BMCI values of around 30 that are typical of various types of hydrotreated distillate fractions that are commonly used as distillate flux for

blending with resid fractions to form marine fuel oils (and/or fuel blending components). However, it has been unexpectedly discovered that fatty acid alkyl esters have substantially greater compatibility for blending with resid fractions while reducing or minimizing formation of sediment and/or sludge. The unexpected compatibility of fatty acid alkyl esters for blending with resid fractions can be further seen in the unexpected difference between BMCI values and solubility blending numbers for fatty acid alkyl ester fractions. It has been discovered that fatty acid alkyl ester fractions have unexpectedly high solubility blending numbers (S_{BN}) relative to the corresponding BMCI values. As a result, when forming a blend of a resid-containing fraction with a fatty acid alkyl ester fraction, the resulting blend can have an unusually high S_{BN} . In some aspects, using a fatty acid alkyl ester fraction as a flux for a resid-containing fraction can provide the unexpected combination of reducing the density, kinematic viscosity, and optionally sulfur content of a blend while also maintaining or increasing the compatibility. This is in contrast to the expected behavior of a blend where flux is added. Conventionally, addition of flux to a resid-containing fraction can reduce one or more of density, kinematic viscosity, and sulfur, but with a corresponding reduction in compatibility.

[0017] A blend of one or more fatty acid alkyl esters with a resid-containing fraction can be referred to as a fuel composition. In this discussion, a fuel composition is understood to refer to a fraction that can be used as a fuel; that can be used as a blending component for forming a fuel; that can be used as a fuel after adding one or more fuel additives; or a combination thereof.

[0018] In some aspects, a blend of one or more fatty acid alkyl esters and a resid-containing fraction can include 5.0 vol% or more of the one or more fatty acid alkyl esters, or 10 vol% or more, or 20 vol% or more, or 30 vol% or more, or 50 vol% or more. For example, the blend can include 5.0 vol% to 80 vol% of the one or more fatty acid alkyl esters, or 10 vol% to 80 vol%, or 20 vol% to 80 vol%, or 50 vol% to 80 vol%, or 5.0 vol% to 60 vol%, or 10 vol% to 60 vol%, or 20 vol% to 60 vol%. The blend can further include 20 vol% or more of a resid-containing fraction, or 40 vol% or more, or 50 vol% or more, such as up to 90 vol% of a resid-containing fraction. Optionally, the blend can further include 35 vol% or less of a secondary distillate flux, or 30 vol% or less, or 20 vol% or less, such as down to including substantially no secondary distillate flux (0.1 vol% or less). For example, the blend can include 5 vol% to 35 vol% of secondary flux, or 5 vol% to 25 vol%. Examples of a secondary flux can include conventional distillate / diesel fractions, renewable diesel fractions (such as hydrotreated vegetable oil), and/or other types of distillate boiling range fractions.

[0019] In various aspects, the resid-containing fraction can be characterized based on the compatibility properties of the resid-containing fraction. For example, the resid-containing

fraction can have one or more of a BMCI of 30 or more, or 40 or more, or 50 or more, or 60 or more, or 70 or more, such as up to 120; a TE of 5 or more, or 20 or more, or 30 or more, or 40 or more, such as up to 80; a solubility blending number (S_{BN}) of 60 or more, or 70 or more, such as up to 120; and/or an insolubility number (I_N) of 30 or more, or 35 or more, such as up to 80. In some aspects, the resid-containing fraction can also be characterized based on difference values. Two types of difference values are defined in this discussion. One difference value is a difference between BMCI and TE for a fraction (a $BMCI - TE$ value). This difference value can be calculated by subtracting the TE value from the BMCI value. For a resid-containing fraction, the $BMCI - TE$ value can be 50 or less, or 40 or less, or 30 or less, or 20 or less, such as down to 0. The second difference value is a difference between S_{BN} and I_N for a fraction (a $S_{BN} - I_N$ difference value). This difference value can be calculated by subtracting the I_N value from the S_{BN} value for a fraction. For a resid-containing fraction, the $S_{BN} - I_N$ difference value can be 40 or less, or 30 or less, such as down to 5 or possibly still lower.

[0020] In some aspects, it may be desirable to form a blend corresponding to a resid-containing fraction and an elevated level of flux, such as a blend including 25 vol% or more of flux, or 30 vol% or more, or 40 vol% or more, such as up to 80 vol% or possibly still higher. In such aspects, one option can be to have substantially all of the elevated level of flux correspond to fatty acid alkyl esters. Another option can be to have the elevated level of flux correspond to a combination of fatty acid alkyl esters and secondary flux. Using an elevated level of flux, where at least portion of the flux corresponds to fatty acid alkyl esters (and optionally other types of renewable distillate fractions), can be beneficial for forming marine fuels that meet or exceed current and future regulatory standards regarding incorporation of renewable material into fuel products. Depending on the aspect, the amount of flux in the blend can correspond to 25 vol% to 80 vol%, or 25 vol% to 50 vol%, or 30 vol% to 80 vol%, or 30 vol% to 50 vol%, or 40 vol% to 80 vol%. In some aspects, substantially all of the flux in the blend can correspond to fatty acid alkyl esters. In other aspects, where at least one secondary flux is used, the amount of fatty acid alkyl ester in the blend can correspond to 10 vol% to 80 vol%, or 10 vol% to 50 vol%, or 15 vol% to 80 vol%, or 15 vol% to 50 vol%, or 20 vol% to 80 vol%, or 20 vol% to 50 vol%. In such aspects, the amount of renewable flux in the blend (i.e., fatty acid alkyl ester plus other renewable distillate, such as hydrotreated vegetable oil) can correspond to 20 vol% to 80 vol%, or 20 vol% to 50 vol%, or 25 vol% to 80 vol%, or 25 vol% to 50 vol%, or 30 vol% to 80 vol%, or 30 vol% to 50 vol%.

[0021] In some aspects, other properties of a resid-containing fraction can include one or more of a T90 distillation point of 550°C or more; a kinematic viscosity at 50°C of 30 cSt or

more, or 100 cSt or more, or 200 cSt or more, such as up to 1000 cSt; a density at 15°C of 0.95 g/cm³ or more, such as up to 1.06 g/cm³; and/or a micro carbon residue content of 5.0 wt% to 15 wt%. In some aspects, the resid-containing fraction can have a sulfur content of 1000 wppm to 10,000 wppm. In some aspects, the resid-containing fraction can have a sulfur content of 0.5 wt% (5000 wppm) or more, or 1.0 wt%, such as up to 5.0 wt%.

[0022] The one or more fatty acid alkyl esters can have various properties. In some aspects, the one or more fatty acid alkyl esters can have a BMCI value of 50 or less, a S_{BN} value of 55 or more, or a combination thereof. Optionally, the S_{BN} value of the one or more fatty acid alkyl esters can be higher than the S_{BN} value of the resid-containing fraction. In some aspects, a fatty acid alkyl ester can include an alkyl group containing between 1 carbon (fatty acid methyl ester) to 10 carbons (fatty acid decyl ester), or 1 to 8 carbons, or 1 to 6 carbons, or 1 to 4 carbons. In some aspects, a fatty acid alkyl ester fraction can include a blend of two or more types of fatty acid alkyl esters. The fatty acid alkyl esters in a blend of fatty acid alkyl esters can correspond to a blend of esters with different fatty acids, a blend of esters with different alkyl groups, or a blend of esters including both different fatty acid and different alkyl groups. In some aspects, a fatty acid alkyl ester fraction can correspond to a fatty acid methyl ester fraction that meets the requirements provided in EN 14214. In some aspects, a fatty acid alkyl ester fraction can correspond to a fraction that meets the requirements described in ASTM D6751. In some aspects, a fatty acid alkyl ester fraction can be a fraction formed at least in part by transesterification of a feedstock corresponding to canola oil; palm oil; palm oil mill effluent; rapeseed oil; corn oil; soybean oil; tallow; cooking oil (such as vegetable cooking oil); used cooking oil (such as used vegetable cooking oil); or a combination thereof.

[0023] The fuel composition (and/or fuel blending composition) formed by blending a resid-containing fraction with one or more fatty acid alkyl esters can also be characterized based on the compatibility properties of the resid-containing fraction. For example, the fuel composition can have a BMCI value of 59 or less, or 55 or less, or 50 or less, such as down to 30 or possibly still lower. Additionally or alternately, the fuel composition can have a BMCI – TE difference value of 30 or less, or 20 or less, or 15 or less, or 12 or less, or 10 or less, such as down to -20 or possibly still lower. Further additionally or alternately, a fuel composition can have a $S_{BN} - I_N$ difference value of 20 or more, or 25 or more, or 30 or more, such as up to 60 or possibly still higher. A $S_{BN} - I_N$ difference value of 20 or more generally indicates a compatible blend. In some aspects, the fuel composition can have one or more of a kinematic viscosity at 50°C of 380 cSt or less, or 180 cSt or less, or 60 cSt or less, such as down to 10 cSt or possibly still lower; a density at 15°C of 1.00 g/cm³ or less, such as down to 0.90 g/cm³; and/or a sulfur content of

10,000 wppm or less, or 5000 wppm or less (such as 4000 wppm to 5000 wppm), or 1000 wppm or less (such as 800 wppm to 1000 wppm), such as down to 10 wppm or possibly still lower. In some aspects, the fuel composition can have a sulfur content of 500 wppm or more, or 800 wppm or more, or 1000 wppm or more, or 2000 wppm or more, or 4000 wppm or more, such as up to 1000 wppm or 5000 wppm.

[0024] The fuel composition (and/or fuel blending composition) can also have a low sediment content and/or a favorable value for the spot test cleanliness rating according to ASTM D4740. In some aspects, the fuel composition can have a sediment content of 0.1 wt% or less, or 0.07 wt% or less, or 0.05 wt% or less, such as down to having substantially no sediment (less than 0.01 wt%). Additionally or alternately, the fuel composition can have a spot test cleanliness rating (ASTM D4740) of 1 or 2.

[0025] When forming a residual marine fuel, in addition to a resid-containing fraction and a fatty acid alkyl ester fraction, any other convenient type of blend component can also be included. Thus, the resid-containing fraction and the fatty acid alkyl ester fraction may be blended with any of the following and any combination thereof to make a fuel oil: low sulfur diesel (sulfur content of less than 500 wppm), ultra low sulfur diesel (sulfur content <10 or <15 ppmw), low sulfur gas oil, ultra low sulfur gasoil, low sulfur kerosene, ultra low sulfur kerosene, hydrotreated straight run diesel, hydrotreated straight run gas oil, hydrotreated straight run kerosene, hydrotreated cycle oil, hydrotreated thermally cracked diesel, hydrotreated thermally cracked gas oil, hydrotreated thermally cracked kerosene, hydrotreated coker diesel, hydrotreated coker gas oil, hydrotreated coker kerosene, hydrocracker diesel, hydrocracker gas oil, hydrocracker kerosene, gas-to-liquid diesel, gas-to-liquid kerosene, hydrotreated vegetable oil, fatty acid methyl esters, non-hydrotreated straight-run diesel, non-hydrotreated straight-run kerosene, non-hydrotreated straight-run gas oil and any distillates derived from low sulfur crude slates, gas-to-liquid wax, and other gas-to-liquid hydrocarbons, non-hydrotreated cycle oil, non-hydrotreated fluid catalytic cracking slurry oil, non-hydrotreated pyrolysis gas oil, non-hydrotreated cracked light gas oil, non-hydrotreated cracked heavy gas oil, non-hydrotreated pyrolysis light gas oil, non-hydrotreated pyrolysis heavy gas oil, non-hydrotreated thermally cracked residue, non-hydrotreated thermally cracked heavy distillate, non-hydrotreated coker heavy distillates, non-hydrotreated vacuum gas oil, non-hydrotreated coker diesel, non-hydrotreated coker gasoil, non-hydrotreated coker vacuum gas oil, non-hydrotreated thermally cracked vacuum gas oil, non-hydrotreated thermally cracked diesel, non-hydrotreated thermally cracked gas oil, hydrotreated fats or oils such as hydrotreated vegetable oil, hydrotreated tall oil, etc., fatty acid methyl ester, Group 1 slack waxes, lube oil aromatic extracts, deasphalted oil,

atmospheric tower bottoms, vacuum tower bottoms, steam cracker tar, any residue materials derived from low sulfur crude slates, LSFO, RSFO, other LSFO / RSFO blend stocks.

[0026] As needed, fuel or fuel blending component fractions may be additized with additives such as pour point improver, cetane improver, lubricity improver, antioxidant, etc. to improve properties and/or meet local specifications.

[0027] In addition to having unexpected benefits for reducing or minimizing sediment or sludge formation in marine residual fuels, use of fatty acid alkyl esters are also beneficial for use in marine residual fuels based on the reduced carbon intensity of fatty acid alkyl esters as a blend component. By using fatty acid alkyl esters as at least a partial replacement for conventional distillate flux when forming a marine residual fuel, the carbon intensity of a marine residual fuel can be reduced by 10% or more, or 15% or more, or 20% or more, such as up to having a 50% reduction or possibly still more.

[0028] The lower carbon intensity of a residual marine fuel including a fatty acid alkyl ester fraction can be realized by using such a fuel in any convenient type of combustion powered device. In some aspects, a marine residual fuel containing a fatty acid alkyl ester fraction can be used as fuel for a combustion engine in a marine vessel or another convenient type of vehicle. Still other types of combustion devices can include generators, furnaces, and other combustion devices that are used to provide heat or power.

Compatibility Characterization of Residual Fractions and Residual Marine Fuels

[0029] The Bureau of Mines Correlation Index (BMCI) provides a method for characterizing the ability of a fuel oil fraction to maintain solubility of compounds such as asphaltenes. The BMCI index can be calculated based on Equation (1):

$$[0030] \quad (1) \text{ BMCI} = \frac{48640}{V_{ABP}} + (473.7 \times d_{60}) - 456.8$$

[0031] In Equation (1), VABP refers to the volume average boiling point (in degrees Kelvin) of the fraction, which can be determined based on the fractional weight boiling points for distillation of the fraction at roughly 10 vol % intervals from ~10 vol % to ~90 vol %. The “d₆₀” value refers to the density in g/cm³ of the fraction at ~60° F. (~16° C.). While this definition does not directly depend on the nature of the compounds in the fraction, the BMCI index value is conventionally believed to provide an indication of the ability of a fuel oil fraction to solvate asphaltenes.

[0032] An additional/alternative method of characterizing the solubility properties of a fuel oil (or other petroleum fraction) can correspond to the toluene equivalence (TE) of a fuel oil, based on the toluene equivalence test as described, for example, in U.S. Pat. No. 5,871,634,

which is incorporated herein by reference with regard to the definitions for and descriptions of toluene equivalence, solubility number (S_{BN}), and insolubility number (I_N).

[0033] For the toluene equivalence test, the procedure specified in AMS 79-004 and/or as otherwise published (e.g., see Griffith, M. G. and Siegmund, C. W., "Controlling Compatibility of Residual Fuel Oils," *Marine Fuels, ASTM STP 878*, C. H. Jones, Ed., American Society for Testing and Materials, Philadelphia, 1985, pp. 227-247, which is hereby incorporated by reference herein) is defined as providing the procedure. Generally, a convenient volume ratio of oil to a test liquid mixture can be selected, such as about 2 grams of fuel oil (with a density of about 1 g/ml) to about 10 ml of test liquid mixture. Then various mixtures of the test liquid mixture can be prepared by blending n-heptane and toluene in various known proportions. Each of these can be mixed with the fuel oil at the selected volume ratio of oil to test liquid mixture. A determination can then be made for each oil/test liquid mixture to determine if the asphaltenes are soluble or insoluble. Any convenient method might be used. One possibility can be to observe a drop of the blend of test liquid mixture and oil between a glass slide and a glass cover slip using transmitted light with an optical microscope at a magnification from $\sim 50\times$ to $\sim 600\times$. If the asphaltenes are in solution, few, if any, dark particles will be observed. If the asphaltenes are insoluble, many dark, usually brownish, particles, usually ~ 0.5 microns to ~ 10 microns in size, can be observed. Another possible method can be to put a drop of the blend of test liquid mixture and oil on a piece of filter paper and let it dry. If the asphaltenes are insoluble, a dark ring or circle will be seen about the center of the yellow-brown spot made by the oil. If the asphaltenes are soluble, the color of the spot made by the oil will be relatively uniform in color. The results of blending oil with all of the test liquid mixtures can then be ordered according to increasing percent toluene in the test liquid mixture. The desired TE value can be between the minimum percent toluene that dissolves asphaltenes and the maximum percent toluene that precipitates asphaltenes. Depending on the desired level of accuracy, more test liquid mixtures can be prepared with percent toluene amounts in between these limits. The additional test liquid mixtures can be blended with oil at the selected oil to test liquid mixture volume ratio, and determinations can be made whether the asphaltenes are soluble or insoluble. The process can be continued until the desired value is determined within the desired accuracy. The final desired TE value can be taken as the mean of the minimum percent toluene that dissolves asphaltenes and the maximum percent toluene that precipitates asphaltenes.

[0034] The above test method for the toluene equivalence test can be expanded to allow for determination of a solubility number (S_{BN}) and an insolubility number (I_N) for a fuel oil sample. If it is desired to determine S_{BN} and/or I_N for a fuel oil sample, the toluene equivalence test

described above can be performed to generate a first data point corresponding to a first volume ratio R_1 of fuel oil to test liquid at a first percent of toluene T_1 in the test liquid at the TE value. After generating the TE value, one option can be to determine a second data point by a similar process but using a different oil to test liquid mixture volume ratio. Alternatively, a percent toluene below that determined for the first data point can be selected and that test liquid mixture can be added to a known volume of the fuel oil until asphaltenes just begin to precipitate. At that point the volume ratio of oil to test liquid mixture, R_2 , at the selected percent toluene in the test liquid mixture, T_2 , can be used the second data point. Since the accuracy of the final numbers can increase at greater distances between the data points, one option for the second test liquid mixture can be to use a test liquid containing 0% toluene or 100% n-heptane. This type of test for generating the second data point can be referred to as the heptane dilution test.

[0035] Based on the toluene equivalence test and heptane dilution test (or other test so that R_1 , R_2 , T_1 , and T_2 are all defined), the insolubility and solubility numbers for a sample can be calculated based on Equations (2) and (3).

[0036] (2)
$$I_N = T_2 - \left[\frac{T_2 - T_1}{R_2 - R_1} \right] R_2$$

[0037] (3)
$$S_{BN} = I_N \left[1 + \frac{1}{R_2} \right] - T_2 / R_2$$

[0038] As noted in U.S. Pat. No. 5,871,634, alternative methods are available for determining the solubility number of a fuel oil that has an insolubility number of zero.

[0039] In this discussion, some S_{BN} and I_N values were determined according to the above procedure. Other S_{BN} and I_N values were determined by calculation based on values measured according to ASTM D7157. For purposes of determining the scope of this description, the calculation described in section 4.2 of the Concawe Report No. 11/19 for determining S_{BN} and I_N should be used. As described in section 4.2 of Concawe Report No. 11/19, ASTM D7157 can be used to determine the parameters “S-value” and “ S_a ”. Based on those parameters, I_N and S_{BN} can be calculated according to Equations 1 and 2, where d_{15} is the density at 15°C in kg/m³.

[0040] (1)
$$I_N = 100 \times (1 - S_a)$$

[0041] (2)
$$S_{BN} = I_N \times [1 + (S\text{-value} - 1) \times d_{15} / 1000]$$

[0042] The sediment generated by a fraction can be characterized according to ISO 10307-2, Procedure A.

Definitions

[0043] All numerical values within the detailed description and the claims herein are modified by “about” or “approximately” the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0044] Unless otherwise specified, for resid-containing fractions, distillation points and boiling points can be determined according to ASTM D7169. For other fractions, distillation points and boiling points can be determined according to ASTM D2887, but for samples that are not susceptible to characterization using ASTM D2887, D7169 can be used.

[0045] A distillate boiling range fraction is defined as a fraction having a T10 distillation point of 140°C or more and a T90 distillation point of 565°C or less. A vacuum gas oil boiling range fraction (also referred to as a heavy distillate) can have a T10 distillation point of 350°C or higher and a T90 distillation point of 535°C or less. A resid fraction is defined as a bottoms fraction. A vacuum resid is defined as a bottoms fraction having a T10 distillation point of 400°C or higher. It is noted that the definitions for distillate boiling range fraction, vacuum gas oil fraction, and resid fraction are based on boiling point only. Thus, a distillate boiling range fraction or a resid fraction can include components that did not pass through a distillation tower or other separation stage based on boiling point.

[0046] With regard to characterizing properties of resid boiling range fractions and/or blends of such fractions with other components to form resid boiling range fuels, a variety of methods can be used. Density of a blend at 15°C (kg / m³) can be determined according ASTM D4052. Sulfur (in wppm or wt%) can be determined according to ASTM D2622, while nitrogen (in wppm or wt%) can be determined according to D5291. Kinematic viscosity at 40°C, 50°C, and/or 100°C can be determined according to ASTM D445. Pour point can be determined according to ASTM D97. Micro Carbon Residue (MCR) content can be determined according to ASTM D4530. The content of n-heptane insolubles can be determined according to ASTM D3279. CCAI is a calculated value that can be derived from other measured quantities. Flash point can be determined according to ASTM D93. The metals content can be determined according to IP 501. Aromatics content can be determined according to D5186. (It is noted that some aromatics contents reported in this discussion were alternatively determined by using 2-dimensional gas chromatography.)

Life Cycle Assessment and Carbon Intensity

[0047] Life cycle assessment (LCA) is a method of quantifying the "comprehensive" environmental impacts of manufactured products, including fuel products, from "cradle to grave". Environmental impacts may include greenhouse gas (GHG) emissions, freshwater impacts, or other impacts on the environment associated with the finished product. The general guidelines for LCA are specified in ISO 14040.

[0048] The "carbon intensity" of a fuel product (e.g. residual fuel) is defined as the life cycle GHG emissions associated with that product (kg CO₂eq) relative to the energy content of that

fuel product (MJ, LHV basis). Life cycle GHG emissions associated with fuel products must include GHG emissions associated with crude oil production; crude oil transportation to a refinery; refining of the crude oil; transportation of the refined product to point of "fill"; and combustion of the fuel product.

[0049] GHG emissions associated with the stages of refined product life cycles are assessed as follows.

[0050] (1) GHG emissions associated with drilling and well completion - including hydraulic fracturing, shall be normalized with respect to the expected ultimate recovery of sales-quality crude oil from the well.

[0051] (2) All GHG emissions associated with the production of oil and associated gas, including those associated with (a) operation of artificial lift devices, (b) separation of oil, gas, and water, (c) crude oil stabilization and/or upgrading, among other GHG emissions sources shall be normalized with respect to the volume of oil transferred to sales (e.g. to crude oil pipelines or rail). The fractions of GHG emissions associated with production equipment to be allocated to crude oil, natural gas, and other hydrocarbon products (e.g. natural gas liquids) shall be specified accordance with ISO 14040.

[0052] (3) GHG emissions associated with rail, pipeline or other forms of transportation between the production site(s) to the refinery shall be normalized with respect to the volume of crude oil transferred to the refinery.

[0053] (4) GHG emissions associated with the refining of crude oil to make liquefied petroleum gas, gasoline, distillate fuels and other products shall be assessed, explicitly accounting for the material flows within the refinery. These emissions shall be normalized with respect to the volume of crude oil refined.

[0054] (5) All of the preceding GHG emissions shall be summed to obtain the "Well to refinery" (WTR) GHG intensity of crude oil (e.g. kg CO₂eq/bbl crude).

[0055] (6) For each refined product, the WTR GHG emissions shall be divided by the product yield (barrels of refined product/barrels of crude), and then multiplied by the share of refinery GHG specific to that refined product. The allocation procedure shall be conducted in accordance with ISO 14040. This procedure yields the WTR GHG intensity of each refined product (e.g. kg CO₂eq/bbl gasoline).

[0056] (7) GHG emissions associated with rail, pipeline or other forms of transportation between the refinery and point of fueling shall be normalized with respect to the volume of each refined product sold. The sum of the GHG emissions associated with this step and the previous step of this procedure is denoted the "Well to tank" (WTT) GHG intensity of the refined product.

[0057] (8) GHG emissions associated with the combustion of refined products shall be assessed and normalized with respect to the volume of each refined product sold.

[0058] (9) The “carbon intensity” of each refined product is the sum of the combustion emissions (kg CO₂eq/bbl) and the “WTT” emissions (kg CO₂eq/bbl) relative to the energy value of the refined product during combustion. Following the convention of the EPA Renewable Fuel Standard 2, these emissions are expressed in terms of the low heating value (LHV) of the fuel, i.e. g CO₂eq/MJ refined product (LHV basis).

[0059] In the above methodology, the dominant contribution for the amount of CO₂ produced per MJ of refined product is the CO₂ formed during combustion of the product. Because the CO₂ generated during combustion is such a high percentage of the total carbon intensity, achieving even small or incremental reductions in carbon intensity has traditionally been challenging. However, because fatty acid alkyl esters (such as fatty acid methyl esters) are derived from biological sources (and therefore consume some CO₂ during growth of the original biological material), fatty acid alkyl esters can have a substantially lower carbon intensity than conventional distillate fractions.

Comparative Blending Examples

[0060] Table 1 shows various properties for a fuel oil (Fuel Oil 1, or FO1), three types of conventional distillate fractions, and two renewable diesel fractions. The conventional distillate fractions represent low sulfur diesel blending components for forming a marine fuel oil from a resid-containing fraction. The renewable diesel fractions correspond to diesel formed from hydrotreated vegetable oil. FO1 represents a conventional resid fraction that could be used in a marine fuel oil, but only if blended with appropriate blend components. For example, the density and the kinematic viscosity of FO1 are too high for some types of residual fuels. Conventionally, this could be corrected by blending FO1 with some type of flux, such as one of the distillate or renewable diesel fractions shown in Table 1.

Table 1 – Blend Components

			FO 1	Dist. 1	Dist. 2	Dist. 3	RD 1	RD 2
Test	Method	Unit						
Density @ 15°C	D4052	g/cm ³	1.010	0.876	0.855	0.836	0.778	0.796
Kinematic Viscosity (KV) @ 40°C	D445	mm ² /s				3.565	2.65	3.739
Kinematic Viscosity (KV) @ 50°C	D445	mm ² /s	473.0	9.8531	4.2735	2.943	2.229	3.076

CCAI	Calculated	-	868	793	795	789	741	746
Distillation - Average Boiling Point	D86	°C				287	290	305
Distillation - Average Boiling Point	D7169	°C		381	325			
Aromatics	2DGC	wt%		43.2	36.8			
Aromatics	D5186	wt%				21.9		
Aromatics	EN 12916	wt%					0.8	5
BHCI	Calculated	-	83.4	32.9	29.9	26.5	-1.7	4.5
Toluene Equivalence (TE)	AM-S 79-004	-	73	0	0	0	0	0
BHCI - TE	-	-	10.9	32.9	29.9	26.5	-1.7	4.5
Oil Compatibility Test	AM-S 1999-011							
Solubility blending number (S_{BN})		-	100	30	30	26		
Incompatibility number (I_N)		-	78	0	0	0		
$S_{BN} - I_N$		-	22	30	30	26		

[0061] In Table 1, Distillate 1, Distillate 2, and Distillate 3 are low sulfur distillate fractions that have BHCI values near 30, while the renewable diesel fractions have BHCI values near 0. This is in contrast to FO1, which has a BHCI value of greater than 80. With regard to toluene equivalence (TE), FO1 has a TE number of 73, which is roughly 10 lower than the BHCI value for FO1. None of the distillate fractions or renewable diesel fractions has a TE greater than 0.

[0062] Table 1 also shows S_{BN} and I_N for the various fractions. As shown in Table 1, FO1 has a S_{BN} of 100 and an I_N of 78. The distillate fractions have S_{BN} values near 30, with an I_N of 0. It is noted that based on both BHCI – TE and $S_{BN} - I_N$, FO1 would be considered a challenging resid fraction for forming a marine fuel oil, as FO1 is already close to the compatibility limit for avoiding sediment formation.

[0063] In order to correct the density and kinematic viscosity of FO1 to levels that satisfy some residual fuel specifications, FO1 would need to be blended in a roughly 80 / 20 volume ratio with a distillate boiling range flux. Table 2 shows calculated properties for blends formed by blending FO1 with each of the distillate or renewable diesel fractions shown in Table 1 in an 80 / 20 volume ratio.

Table 2 – Resid Blends with 20 vol% Distillate

			FO 1	FO 1 + 20% Dist 1	FO 1 + 20% Dist 2	FO 1 + 20% Dist 3	FO 1 + 20% RD 1	FO 1 + 20% RD 2
Test	Method	Unit						
Density @ 15°C	D4052	g/cm ³	1.010	0.983	0.979	0.975	0.963	0.967
Kinematic Viscosity (KV) @ 50°C	D445	mm ² /s	473.0	161.5	111.8	92.5	79.3	94.7
CCAI	Calculated	-	868	853	853	852	843	844
BMCI	Calculated	-	83.4	73.3	72.7	72.0	66.4	67.6
Toluene Equivalence (TE)	AM-S 79- 004	-	73	72.5	72.5	73	73	73
BMCI - TE	-	-	10.9	0.8	0.2	-0.5	-6.1	-4.9
Oil Compatibility Test	AM-S 1999-011							
Solubility blending number (S _{BN})		-	100	86	86	85.2		
Incompatibility number (I _N)		-	78	78	78	78		
S _{BN} - I _N		-	22	8	8	7.2		

[0064] As shown in Table 2, the calculated blends including FO1 and 20% of the various distillate / renewable diesel fractions all have a density and kinematic viscosity that is roughly suitable for satisfying some residual marine fuel specifications. However, the resulting blends also have BMCI – TE values near 0 or even below 0. This indicates a high likelihood of sediment formation, meaning that the resulting blend does not meet all specifications from, for example, a residual fuel oil specification in ISO 8217. It is noted that the difference between S_{BN} and I_N for the three distillate blends also indicates a blend that will result in sediment formation.

[0065] Table 3 shows calculated blends that are similar to Table 2, but with 50 vol% of each distillate / renewable diesel fraction, rather than 20 vol%. As shown in Table 3, all of the blends including 50 vol% of distillate or renewable diesel have negative values for BMCI – TE, indicating a high likelihood of sediment formation.

Table 3 – Resid Blends with 50 vol% Distillate

			FO 1	FO 1 + 50% Dist 1	FO 1 + 50% Dist 2	FO 1 + 50% Dist 3	FO 1 + 50% RD 1	FO 1 + 50% RD 2
Test	Method	Unit						
Density @ 15°C	D4052	g/cm ³	1.010	0.943	0.932	0.923	0.894	0.903

Kinematic Viscosity (KV) @ 50°C	D445	mm ² /s	473.0	44.83	23.02	16.71	13.05	17.38
CCAI	Calculated	-	868	831	831	828	804	807
BMCi	Calculated	-	83.4	58.2	56.7	55.0	40.9	44.0
Toluene Equivalence (TE)	AM-S 79-004	-	73	73	73	73	73	73
BMCi - TE	-	-	10.9	-14.4	-15.9	-17.6	-31.6	-28.5
Oil Compatibility Test	AM-S 1999-011							
Solubility blending number (S _{BN})		-	100	65	65	63		
Incompatibility number (I _N)		-	78	78	78	78		
S _{BN} - I _N		-	22	-13	-13	-15		

Blends of Resid-Containing Fractions with Fatty Acid Alkyl Esters

[0066] The following example use fatty acid methyl esters (FAME) to illustrate the benefits of using fatty acid alkyl esters as blend components for forming marine residual fuels.

[0067] FIG. 1 shows properties for various fatty acid methyl ester (FAME) fractions and several fuel oils. It is noted that FO1 in FIG. 1 is the same as FO1 from Tables 1 – 3. As shown in FIG. 1, the FAME fractions have BMCi values of roughly 40 or less. This is similar to the BMCi values of roughly 30 for the distillate fractions. However, it has been discovered that fatty acid alkyl ester fractions have unexpectedly high S_{BN} values. As shown in FIG. 1, the FAME fractions have S_{BN} values between 65 and 85. Normally, a fraction with a BMCi of 40 or less would be expected to also have a S_{BN} value of 50 or less.

[0068] As described above, FO1 has a relatively low BMCi – TE value and low difference value between S_{BN} and I_N. Thus, FO1 is a resid fraction that would be expected to present challenges when attempting to blend with a distillate flux. FO3 also has low values for BMCi – TE and S_{BN} – I_N. It is noted that FO3 has a spot test cleanliness rating (ASTM D4740) of 1. FO4 is potentially more suitable for blending, but still has the potential for incompatibility when blended with larger amounts of conventional distillate.

[0069] FIG. 2 shows a blended product made from each of the FAME fractions in FIG. 1 in combination with either FO1 or FO3. The blended products in FIG. 2 correspond to 80 vol% of FO1 or FO3 blended with 20 vol% of one of the FAME fractions. The BMCi for each blended product was calculated based on the weighted average of the BMCi values for the resid-

containing fraction and the FAME fraction. The Toluene Equivalence, however, was measured for each blended product.

[0070] As shown in FIG. 2, each of the blended products in FIG. 2 has a BMCI – TE value of less than 15. This indicates that each of the blended products in FIG. 2 would be expected to have sediment formation. However, as shown for the blends involving FO3 and FAME 1, FAME 2, and FAME 3, the measured sediment formation was less than 0.01 wt%. Additionally, the blends involving FO3 and FAME 1, FAME 2, or FAME 3 all maintained a spot test cleanliness rating (ASTM D4740) of 1. This demonstrates the unexpected benefit of blending a fatty acid alkyl ester fraction with a resid-containing fraction for forming marine fuel oils. This unexpected benefit is due in part to the high S_{BN} values for the FAME fractions. As shown in FIG. 2, the solubility blending number for each of the blended fractions is equal to or greater than the corresponding solubility blending number for the resid-containing fraction used to form the blend. In fact, based on the solubility blending number values, the addition of the fatty acid alkyl ester fractions appears to stabilize the resulting blends.

[0071] FIG. 3 shows another series of blended products based on blending FO4 with FAME 1, FAME 2, and FAME 3. For the blended products in FIG. 3, 50 vol% of FO4 was blended with 50 vol% of a FAME fraction. Although FO4 has a large value for BMCI – TE of 31.8, it would be expected conventionally that attempting to blend FO4 with 50 vol% of a distillate flux would result in sediment formation. For example, the most favorable distillate fraction for blending shown in Table 1 above is Distillate 1, which has a BMCI value of 32.9. Based on calculated values, a blend of 50 vol% FO4 and 50 vol% Distillate 1 would be expected to have a BMCI value of 53.9. The calculated TE value for such a blend would be expected to be roughly the TE value for FO4 of 43. Thus, a blend of 50 vol% FO4 and 50 vol% Distillate 1 would have a calculated BMCI – TE value of roughly 11, which is less than 15 (or less than 12) and therefore indicates a blend that would likely be incompatible.

[0072] As shown in FIG. 3, the calculated BMCI – TE values for the blended fractions are all less than 15, indicating a likelihood for sediment formation. However, the measured sediment formation for the blended fractions was either 0.01 wt% or less than 0.01 wt% indicating that the blended fractions would satisfy the sediment formation requirement for various types of marine fuel oils. Due to the high S_{BN} value for FO4 (79), the blend of FO4 with FAME 1 had a lower S_{BN} value (73) than the neat FO4 fraction. This was the blended product that showed 0.01 wt% of sediment formation. It is noted that the blends of FO4 with FAME 2 and FAME 3 had S_{BN} values (82 and 79, respectively) that were equal to or greater than the S_{BN} value of the neat FO4 fraction. This represents another unexpected benefit of using fatty acid methyl esters (or more

generally fatty acid alkyl esters) as a blend component. Due to the unusually high S_{BN} values, blending fatty acid methyl esters (or more generally fatty acid alkyl esters) with some resid-containing fractions can provide the unexpected benefit of reducing density and kinematic viscosity while also maintaining or even improving the compatibility of the resulting blend. This is in contrast to conventional addition of flux to a resid-containing fraction, where it would be expected that addition of flux would provide the traditional benefit of reducing density and/or kinematic viscosity, but at the cost of also reducing the compatibility of the resulting blend.

[0073] Based on the unexpectedly high S_{BN} values of fatty acid alkyl esters, still greater amounts of fatty acid alkyl ester can be blended with a resid-containing fraction without causing sediment formation in the resulting blended product. Table 4 shows a modeled blending example of blending FO3 with FAME 1 in a volume ratio of 30 vol% FO3 to 70 vol% FAME 1.

Table 4 – Model Blend with 70 vol% Fatty Acid Alkyl Ester

			FO 3	FO 3 + 70% FAME 1
Test	Method	Unit		
Density @ 15°C	D4052	g/cm ³	0.963	0.905
Kinematic Viscosity (KV) @ 50°C	D445	mm ² /s	217.3	8.40
CCAI	Calculated	-	830	826
Distillation – Average Boiling Point	D7169	°C	483	
BMCI	Calculated	-	64.1	46.6
Toluene Equivalence (TE)	AM-S 79-004	-	43	43
BMCI - TE	-	-	21.1	3.6
Oil Compatibility Test	AM-S 1999-011			
Solubility blending number (S_{BN})		-	61	81
Incompatibility number (I_N)		-	38	38
$S_{BN} - I_N$		-	23	43

[0074] As shown in Table 4, the modeled blend of 30 vol% FO3 and 70 vol% FAME 1 has a predicted BMCI – TE value of 3.6. For a conventional blend, this would indicate that sediment formation was likely. However, due to the high S_{BN} value of FAME 1, the modeled blend in

Table 4 has a higher S_{BN} value than the neat FO3 fraction. As a result, even though the model blend in Table 4 shows addition of 70 vol% of FAME 1 to FO3, the model blend has a $S_{BN} - I_N$ value above 40, indicating no sediment formation.

Blends Including Fatty Acid Alkyl Ester and Conventional Distillate

[0075] Based on the ability of fatty acid alkyl esters to maintain or even improve compatibility in blends including a resid-containing fraction, fatty acid alkyl esters can also be used in combination with conventional distillate fractions. Using a mixture of fatty acid alkyl ester fraction(s) and conventional distillate fraction(s) as a flux for resid-containing fraction(s) can allow for greater flexibility when blending to form marine fuel products.

[0076] FIG. 4 shows a series of model blends that were formed using a combination of FO3 (from FIG. 1), FAME 1 (from FIG. 1), and Distillate 1 (from Table 1). The compatibility characteristics for the model blends shown in FIG. 4 were based on calculation of compatibility characteristics based on ideal blending, where BMCI and S_{BN} values are based on weighted averages of the blend components while TE and I_N values are based on the corresponding value for FO3.

[0077] As shown in FIG. 4, the BMCI – TE values for all of the blends are substantially below 15, indicating that under conventional blending, all of the blends would be considered to have too high of a potential for sediment formation. However, as shown by the $S_{BN} - I_N$ difference values, adding sufficient amounts of fatty acid alkyl ester can overcome the compatibility issues that are created by adding the distillate flux. As a result, blends including up to 50 vol% (or more) of combined fatty acid alkyl ester and distillate flux can be added to a resid-containing fraction while still reducing or minimizing sediment formation to acceptable levels.

Additional Comparative Example – Aryl Ester

[0078] The unexpected benefits of using fatty acid alkyl esters as a blend component with resid-containing fractions were not observed with other types of esters. Table 5 shows examples of blending an aryl ester, phenethyl octanoate, with a resid-containing fraction (FO2). In the example shown in Table 5, the resid-containing fraction is already prone to sediment formation. This is indicated by both the BMCI – TE value of 7.5, and confirmed by the measured sediment value of 0.49 wt%. The aryl ester fraction had a BMCI value of 83, which is greater than the BMCI value of 73.5 for FO2.

[0079] As shown in Table 5, the aryl ester did not provide the unexpected benefits of the fatty acid alkyl ester fractions. Although the BMCI value of the aryl ester was greater than the BMCI value of FO2, each of the blends shown in Table 5 has a higher measured sediment value than the measured sediment for the neat FO2. This indicates that the addition of the aryl ester

decreased the compatibility of the blend, as opposed to the addition of the fatty acid alkyl esters, which appeared to increase the compatibility of the blend. It is believed that the reduction in sediment amount as the amount of aryl ester is increased is due in part to dilution.

Table 5 – Blends with Aryl Ester

			FO 2	PEO	96% FO 2 + 4 % PEO	83% FO 2 + 17 % PEO	66% FO 2 + 34 % PEO
Test	Method	Unit					
Density @ 15°C	D4052	g/cm ³	0.986	0.958	0.985	0.981	0.977
Kinematic Viscosity (KV) @ 50°C	D445	mm ² /s	247.40				
CCAI	Calculated	-	852				
Distillation - Average Boiling Point	D86	°C		295			
BMCi	Calculated	-	73.5	83.0	73.8	75.1	76.7
Toluene Equivalence (TE)	AM-S 79- 004	-	66	0	66	71	73
BMCi - TE	-	-	7.5	83.0	7.8	9.1	10.7
Total Sediment Existent (TSE)	ISO 10307-1	wt%	0.49		0.95	0.81	0.70

Additional Embodiments

[0080] Embodiment 1. A fuel or fuel blending composition comprising 20 vol% or more of a resid-containing fraction and 5 vol% to 80 vol% of one or more fatty acid alkyl esters, the one or more fatty acid alkyl esters comprising a BMCi of 50 or less and a S_{BN} of 55 or more.

[0081] Embodiment 2. The fuel or fuel blending composition of Embodiment 1, wherein the resid-containing fraction comprises a BMCi – TE difference value of 50 or less, or wherein the fuel composition comprises a BMCi – TE difference value of 15 or less, or a combination thereof.

[0082] Embodiment 3. The fuel or fuel blending composition of any of the above embodiments, wherein the fuel composition comprises 20 vol% or more of the one or more fatty acid alkyl esters.

[0083] Embodiment 4. The fuel or fuel blending composition of any of the above embodiments, wherein the S_{BN} of the one or more fatty acid alkyl esters is greater than a S_{BN} of the resid-containing fraction, or wherein the one or more fatty acid alkyl esters comprise one or more fatty acid methyl esters, or a combination thereof.

[0084] Embodiment 5. The fuel or fuel blending composition of any of the above embodiments, wherein the fuel or fuel blending composition comprises 25 vol% or more of a renewable flux, or wherein the fuel or fuel blending composition comprises 10 vol% or more of the one or more fatty acid alkyl esters, or a combination thereof.

[0085] Embodiment 6. The fuel or fuel blending composition of any of the above embodiments, further comprising 5 vol% to 25 vol% of a secondary flux, the secondary flux comprising a BMCI of 40 or less and a S_{BN} of 50 or less.

[0086] Embodiment 7. The fuel or fuel blending composition of any of the above embodiments, wherein the resid-containing fraction comprises a $S_{BN} - I_N$ difference value of 40 or less, or wherein the fuel composition comprises a $S_{BN} - I_N$ difference value of 20 or more, or a combination thereof.

[0087] Embodiment 8. The fuel or fuel blending composition of any of the above embodiments, wherein the resid-containing fraction comprises a kinematic viscosity at 50°C of 30 cSt or more, or wherein the resid-containing fraction comprises a density at 15°C of 0.95 g/cm³ or more, or a combination thereof.

[0088] Embodiment 9. The fuel or fuel blending composition of any of the above embodiments, wherein the resid-containing fraction has a T90 distillation point of 550°C or more, or wherein the resid-containing fraction comprises 5.0 wt% or more of micro carbon residue, or a combination thereof.

[0089] Embodiment 10. The fuel or fuel blending composition of any of the above embodiments, wherein the fuel or fuel blending composition comprises a kinematic viscosity at 50°C of 380 cSt or less, or wherein the fuel or fuel blending composition comprises a kinematic viscosity at 50°C of 60 cSt or less.

[0090] Embodiment 11. The fuel or fuel blending composition of any of the above embodiments, wherein the fuel or fuel blending composition comprises a sediment level of 0.1 wt% or less, or wherein the fuel or fuel blending composition comprises 5000 wppm or less of sulfur, or a combination thereof.

[0091] Embodiment 12. The fuel or fuel blending composition of any of the above embodiments, wherein the fuel or fuel blending composition comprises a sulfur content of 1000 wppm or less, or a sulfur content of 800 wppm or more, or a combination thereof.

[0092] Embodiment 13. The fuel or fuel blending composition of any of the above embodiments, wherein the one or more fatty acid alkyl esters comprise one or more fatty acid methyl esters.

[0093] Embodiment 14. Use of a fuel comprising the fuel or fuel blending composition of any of Embodiments 1 to 13 as a fuel in a combustion device.

[0094] Embodiment 15. A method for forming a fuel or fuel blending composition according to any of Embodiments 1 to 13, comprising blending 20 vol% or more of a resid-containing fraction and 5 vol% to 80 vol% of one or more fatty acid alkyl esters to form the fuel composition, the one or more fatty acid alkyl esters comprising a BMCI of 50 or less and a S_{BN} of 55 or more.

[0095] While the present invention has been described and illustrated by reference to particular embodiments, those of ordinary skill in the art will appreciate that the invention lends itself to variations not necessarily illustrated herein. For this reason, then, reference should be made solely to the appended claims for purposes of determining the true scope of the present invention.