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(54) **Title:** BITUMEN PARTIAL UPGRADING

(57) **Abrégé/Abstract:**

Systems and methods are provided for partial upgrading of oil sands. The systems and methods include forming a low-asphaltene bitumen using a modified paraffinic froth treatment, followed by visbreaking and/or other thermal cracking of the low-asphaltene bitumen. By using a modified paraffinic froth treatment to form a low-asphaltene bitumen, potential coke precursors are removed from the feed prior to thermal cracking while reducing or minimizing the loss of other hydrocarbons in the bitumen. Removing the coke precursors can allow a substantial increase in thermal cracking severity while producing a cracked product containing a reduced or minimized content of coke particles.

ABSTRACT

Systems and methods are provided for partial upgrading of oil sands. The systems and methods include forming a low-asphaltene bitumen using a modified paraffinic froth treatment, followed by visbreaking and/or other thermal cracking of the low-asphaltene bitumen. By using a modified paraffinic froth treatment to form a low-asphaltene bitumen, potential coke precursors are removed from the feed prior to thermal cracking while reducing or minimizing the loss of other hydrocarbons in the bitumen. Removing the coke precursors can allow a substantial increase in thermal cracking severity while producing a cracked product containing a reduced or minimized content of coke particles.

BITUMEN PARTIAL UPGRADING

FIELD

[0001] Systems and methods are provided for partial upgrading of bitumens derived from paraffinic froth treatment.

BACKGROUND

[0002] Oil sands are a type of non-traditional petroleum source that remains challenging to fully exploit. Due to the nature of oil sands, substantial processing can be required at or near the extraction site just to create bitumen / crude oil fractions that are suitable for transport. However, oil sands extraction sites are also often in geographically remote locations, which can substantially increase the construction and maintenance costs for any processing equipment that is used at the oil sands site.

[0003] One option for transporting bitumen away from an extraction site is by adding a diluent to the bitumen. For example, a naphtha boiling range diluent can be added to produce a diluted bitumen. Unfortunately, for many types of bitumen, the amount of diluent required to can correspond to 25 vol% or more of the diluted bitumen.

[0004] Another option for upgrading a bitumen for transport is to form a synthetic crude oil by converting substantially all of the 566°C+ components in the bitumen. The conversion of the 566°C+ components of the bitumen can be performed in various ways, such as by coking or slurry hydroconversion. Converting bitumen to synthetic crude oil is effective for forming a product suitable for pipeline transport. However, the costs of performing the bitumen conversion are substantial, with regard to both capital equipment and processing costs.

[0005] Mild thermal cracking, such as visbreaking, is a lower cost alternative for upgrading of bitumen feeds. However, conventional methods for mild thermal cracking have been limited in the amount of upgrading that can be performed. This is in part due to the need to reduce or minimize formation of incompatible compounds in the mild thermal cracking environment. Due to such limitations, conventional methods of mild thermal cracking produce a bitumen that can still require substantial diluent addition in order to achieve pipeline transport specifications.

[0006] What is needed are improved systems and methods for performing partial upgrading of bitumen that can reduce or minimize the amount of diluent that is needed to form a product suitable for transport.

[0007] U.S. Patent 4,428,824 describes methods for partially upgrading a petroleum resid feed using solvent deasphalting and visbreaking. The resid feed is first exposed to solvent deasphalting conditions to form deasphalted oil and a remaining portion that contains asphaltenes. The deasphalted oil is then exposed to visbreaking conditions to form a visbroken effluent. The remaining portion of asphaltenes are then combined with the visbroken effluent to form combined visbreaking product. Removing the asphaltenes by forming deasphalted oil is described as allowing higher severity visbreaking to be performed on the deasphalted oil without causing excessive coke formation.

[0008] U.S. Patent 4,379,747 describes methods for performing visbreaking on a combination of heavy hydrocarbon oil and coal particles. An initial visbreaking process is performed on the heavy hydrocarbon oil. The visbroken effluent is mixed with coal particles, and then exposed to a second, less severe visbreaking process. The second visbroken effluent can then be exposed to solvent deasphalting conditions to precipitate out asphaltic solids. The deasphalting solvent can then be distilled to recover the liquid portion of the second visbroken effluent. The method is described as being beneficial for demetallation of a feed.

[0009] U.S. Patent 4,615,791 describes an example of visbreaking of a resid feedstock in the presence of a hydrogen donor solvent.

SUMMARY

[0010] In various aspects, a method for forming a partially upgraded bitumen is provided. The method includes performing a paraffinic froth treatment on a feed comprising 5.0 wt% or more of particulate matter and 10 wt% or more of n-pentane insolubles to form a bitumen comprising 1.0 wt% to 8.0 wt% of n-pentane insolubles, a first API gravity, and a kinematic viscosity at 10°C of 10,000 cSt or more. Optionally, the first API gravity can correspond to

an API gravity of 14° or less. The bitumen can then be exposed to a thermal cracking process to form 0.5 wt% or less coke and a partially upgraded bitumen comprising an upgraded API gravity. Optionally, the partially upgraded bitumen can have a kinematic viscosity at 10°C of 1000 cSt or less. Optionally, the upgraded API gravity can be an API gravity of 15° or more. Optionally, the upgraded API gravity can be greater than the first API gravity by 5° or more.

DETAILED DESCRIPTION

[0011] 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.

Overview

[0012] In various aspects, systems and methods are provided for partial upgrading of oil sands. The systems and methods include forming a low-asphaltene bitumen using a modified paraffinic froth treatment, followed by visbreaking and/or other thermal cracking of the low-asphaltene bitumen. By using a modified paraffinic froth treatment to form a low-asphaltene bitumen, potential coke precursors are removed from the feed prior to thermal cracking while reducing or minimizing the loss of other hydrocarbons in the bitumen. Removing the coke precursors can allow a substantial increase in thermal cracking severity while producing a cracked product containing a reduced or minimized content of coke particles. Further advantages can be realized when the thermal cracking (such as visbreaking) is performed in the presence of a hydrogen-containing stream and/or a hydrogen donor solvent.

[0013] The increase in thermal cracking severity is enabled in part by forming a low-asphaltene bitumen using a modified paraffinic froth treatment. Paraffinic froth treatment is a method that can be used to convert raw oil sands into a bitumen with reduced water, particulate, and asphaltene content. Conventionally, the conditions for a paraffinic froth treatment are selected to reduce the particle content of the bitumen to a desired level while increasing or maximizing the amount of hydrocarbons retained in the bitumen. For example, a conventional paraffinic froth treatment process can reduce the water content to 2000 wppm or less and can reduce the particulate content to 300 wppm or less. In particular, the conditions are selected to remove particles (or more generally particulate matter) to a desired level while retaining as many n-pentane insolubles as possible in the bitumen. An advantage of paraffinic froth treatment is that the amount of particle reduction is typically sufficient so that further treatment to remove particulate matter is not required prior to pipeline or other transport.

[0014] Conventionally, retaining C_5 asphaltenes (n-pentane insolubles) in a paraffinic froth treatment bitumen is desirable for a variety of reasons. First, the C_5 asphaltenes represent additional bitumen yield. Prior to a paraffinic froth treatment, n-pentane insolubles can correspond to 15 wt% to 25 wt%, or 15 wt% to 20 wt%, of the hydrocarbons in a froth (i.e., the feed to a froth treatment). Thus, allowing all of the n-pentane insolubles to be removed would result in a substantial yield loss. Under a conventional paraffinic froth treatment, the n-pentane insolubles content is reduced to roughly 10 wt% to 15 wt%, so that the bitumen yield loss during particle removal is reduce or minimized. In addition to mitigating bitumen yield loss, retaining asphaltenes using conventional paraffinic froth treatment conditions can also be beneficial for asphalt production. If substantially all of the C_5 asphaltenes are removed from a bitumen, the bitumen will no longer contain an appropriate fraction that would allow asphalt production. By retaining a portion of the C_5 asphaltenes in the bitumen, asphalt production can still occur, although air oxidation or another process may be beneficial for improving the asphalt properties.

[0015] In contrast to a conventional paraffinic froth treatment, in various aspects herein, a paraffinic froth treatment with increased severity can be used to form a low asphaltene bitumen. Instead of the conventional forming of a bitumen with 10 wt% to 15 wt% n-pentane insolubles content, a modified paraffinic froth treatment can be used to produce a bitumen containing 1.0 wt% to 8.0 wt% n-pentane insolubles, or 3.0 wt% to 5.0 wt%. This corresponds to retaining some C_5 asphaltenes, but in a sufficiently low amount to allow a subsequent visbreaking process to be performed at a substantially increased severity.

[0016] The severity of a visbreaking process for visbreaking of bitumen can be limited based on either coke formation or asphaltene formation within the visbreaking process environment. Excessive coke formation is a problem due to accumulation of coke on surfaces within the visbreaking process environment. Asphaltenes can also form in the visbreaking environment, and can lead to creation of an incompatible phase if a sufficient amount of asphaltenes are formed. Whether coke formation or asphaltene formation is the limiting factor is dependent on the nature of the bitumen feed.

[0017] When performing visbreaking on a bitumen formed from a conventional paraffinic froth treatment, the C_5 asphaltenes (n-pentane insolubles) already present in the bitumen mean that only a limited amount of additional asphaltene formation can occur prior to creation of an incompatible phase. For a bitumen formed from a conventional paraffinic froth treatment, asphaltene formation is the limiting factor. In various aspects, it has been discovered that using a modified paraffinic froth treatment can reduce the C_5 asphaltene content by a sufficient amount so that significantly more cracking can be performed prior to creating coke and/or incompatible compounds. It has further been discovered that reducing the content of n-pentane insolubles in a bitumen product from a paraffinic froth treatment process to 1.0 wt% to 8.0 wt% (or 3.0 wt% to 5.0 wt%) can allow production of a bitumen where the limitation on severity due to coke formation is greatly reduced, while still allowing some C_5 asphaltenes to be retained in the bitumen. This means that a modified paraffinic froth treatment can provide a superior yield of bitumen (relative to performing a higher severity process that rejects all C_5 asphaltenes, such as propane solvent deasphalting) while still enabling a substantial increase in visbreaking severity.

[0018] The increased severity during visbreaking can allow the resulting visbroken bitumen to approach much closer to desirable transport properties. This can substantially reduce the amount of additional diluent that is needed to achieve target pipeline transport standards. In some aspects, such as aspects where the visbreaking is performed in the presence of a hydrogen-containing stream and/or a hydrogen donor solvent, the visbroken bitumen may be suitable for pipeline transport without any further addition of diluent.

Definitions

[0019] In this discussion, the relative severity of visbreaking processes can be compared by referring to a severity index. Severity (or severity index, SI) is a function of reaction time and temperature used during visbreaking. It provides an indication of the severity of the reaction and can be used to compare results of reactions carried out at different conditions. The severity index is defined as:

$$SI = t\,exp\left[-\frac{E}{R}\left(\frac{1}{T} - \frac{1}{700}\right)\right] \qquad (1)$$

[0020] In Equation (1), t is the reaction time in seconds, E is the activation energy associated with bitumen thermal cracking, R is the universal gas constant and T is the reaction temperature. The severity index equals the time required in seconds at 427°C (700°K) to achieve the same degree of reaction (e.g. pitch conversion). For conversion of bitumen, E can generally be set to a value between 50 kcal/mol to 55 kcal/mol.

[0021] In this discussion, C_5 asphaltenes are defined as n-pentane insolubles. The content of n-pentane insolubles in a sample is determined according to the method in ASTM D4055.

[0022] In this discussion, a hydrogen donor solvent refers to a solvent that can be added to bitumen during processing to allow for higher severity while reducing or minimizing coking. The hydrogen donor solvent can have a higher hydrogen to carbon ratio (i.e., a higher hydrogen content) than the bitumen. For bitumen processing, a recycle fraction from a partially upgraded effluent, such as a recycled naphtha, distillate and/or vacuum gas oil fraction, can be a suitable hydrogen donor solvent. In some aspects, it is noted that addition of a hydrogen donor solvent can potentially provide an additional benefit by acting as a diluent for the feed. This can improve flow properties, such as kinematic viscosity and/or density, which could facilitate cracking.

[0023] In this discussion, a "C_x" hydrocarbon refers to a hydrocarbon compound that includes "x" number of carbons in the compound. A stream containing "C_x – C_y" hydrocarbons refers to a stream composed of one or more hydrocarbon compounds that includes at least "x" carbons and no more than "y" carbons in the compound. It is noted that a stream comprising C_x – C_y hydrocarbons may also include different types of hydrocarbons, unless otherwise specified.

[0024] In various aspects of the invention, reference may be made to one or more types of fractions generated during distillation of a petroleum feedstock, intermediate product, and/or product. Such fractions may include naphtha fractions, distillate fuel fractions, and vacuum gas oil fractions. Each of these types of fractions can be defined based on a boiling range, such as a boiling range that includes at least 90 wt% of the fraction, or at least 95 wt% of the fraction. For example, for naphtha fractions, at least 90 wt% of the fraction, or at least 95 wt%, can have a boiling point in the range of 85°F (29°C) to 350°F (177°C). It is noted that 29°C roughly corresponds to the boiling point of isopentane, a C_5 hydrocarbon. For a distillate fuel fraction, at least 90 wt% of the fraction, or at least 95 wt%, can have a boiling point in the range of 350°F (177°C) to 650°F (343°C). For a vacuum gas oil fraction, at least 90 wt% of the fraction, or at least 95 wt%, can have a boiling point in the range of 650°F (343°C) to 1050°F (566°C). Fractions boiling at temperatures below the naphtha range can sometimes be referred to as light ends. Fractions boiling at temperatures above the vacuum gas oil range can be referred to as vacuum resid fractions or pitch fractions.

[0025] In this discussion, thermal cracking conditions refer to conditions where a feed (such as a bitumen) is exposed to a temperature of 350°C or higher in a reaction environment that substantially does not include a particulate catalyst (i.e., less than 0.1 wt% of catalyst particles). Added hydrogen and/or a hydrogen donor solvent may be present in the thermal cracking environment.

[0026] In this discussion, the boiling range of components in a feed, intermediate product, and/or final product may alternatively be described based on describing a weight percentage of components that boil within a defined range. The defined range can correspond to a range with an lower boiling temperature bound, such as components that boil at less than 177°C (referred to as 177°C-); a range with a upper boiling temperature bound, such as components that boil at greater than 566°C (referred to as 566°C+); or within or outside of a range with both a lower bound and an upper bound, such as 343°C – 566°C.

[0027] Preparing heavy hydrocarbon feeds for pipeline transport often involves achieving target values for a plurality of separate properties. First, the viscosity of the processed heavy hydrocarbon feed needs to be suitable or roughly suitable for pipeline transport. This can correspond to, for example, having a kinematic viscosity at 10°C of 350 cSt or less, such as down to 250 cSt, or possibly still lower. Second, the density of the processed heavy hydrocarbon feed needs to be suitable or roughly suitable for pipeline transport. This can correspond to, for example, having an API Gravity of 18° or more, or 19° or more.

[0028] In this discussion, API gravity can be determined according to ASTM D1298. API gravity values reported herein correspond to API gravity at 15°C. Kinematic viscosity can be determined according to ASTM D445 (if a bitumen has a kinematic viscosity of greater than 200,000, ASTM D2170 can be used instead.)

Paraffinic Froth Treatment of Oil Sands Froth

[0029] The particle content and/or content of other non-petroleum materials of oil sands can be quite large, corresponding to 30 wt% or more of the product. An initial reduction in the particle content can be performed by first extracting the raw product with water. The Clark hot water extraction process is an example of an extraction process for oil sands. Air is typically bubbled through the water to assist in separating the bitumen from the non-petroleum material. This will remove a large proportion of the solid, non-petroleum material in the raw product. However, smaller particles of non-petroleum particulate solids will typically remain with the oil phase at the top of the mixture. This top oil phase is sometimes referred to as a froth. The particulate matter in this froth can still correspond to 5.0 wt% or more of the froth, or 10 wt% or more, such as up to 20 wt% or possibly still higher. Additionally, the combined particle and water content of the froth can correspond to 40 wt% or more of the froth.

[0030] The resulting washed oil sands can include 5.0 wt% to 20 wt%, or 5.0 wt% to 15 wt%, or 10 wt% to 15 wt%, of particulate matter and another 25 wt% to 35 wt% of water. Separation of the smaller non-petroleum particulate solids can be achieved by adding an extraction solvent to the froth of the aqueous mixture. This is referred to as a “froth treatment”. Examples of typical paraffinic solvents include isopentane, pentane, and other light paraffins (such as $C_5 - C_8$ paraffins) that are liquids at room temperature. When such a paraffinic solvent is used, the process can be referred to as a paraffinic froth treatment. Adding the extraction solvent results in a two phase mixture, with the crude and the extraction solvent substantially forming one of the phases. The majority of the smaller particulate solids of non-petroleum material are “rejected” from the oil phase and join the substantially aqueous phase of the process. The crude oil and solvent phase can then be separated from the aqueous phase, followed by recovery of the extraction solvent for recycling.

[0031] Conventionally, the goal of a paraffinic froth treatment is to force the froth to form at least two phases, with the bitumen primarily concentrated in one phase and the water and particles primarily concentrated in one (or more) other phases. This results in a bitumen product with a combined water and particulate matter content of 0.25 wt% or less, with the particulate matter corresponding to less than 0.03 wt%, or less than 0.01 wt%. Conventionally, the goal of a paraffin froth treatment is to reduce the particle content in the bitumen product down to a level at or near the standard for pipeline transport. A conventional paraffinic froth treatment can be performed at a solvent to feed weight ratio of 1.4 : 1 to 1.7 : 1, and at a mixing temperature of 60°C to 80°C. A suitable solvent can be a mixture of n-pentane and isopentane. The solvent and the conditions can be selected to achieve an n-pentane insolubles content in the resulting bitumen of 10 wt% to 15 wt%. Such conventional paraffinic froth treatment conditions typically result in rejection of 30 wt% to 60 wt% of the n-pentane insolubles.

[0032] In various aspects, instead of performing a conventional paraffinic froth treatment, a paraffinic froth treatment can be performed under modified conditions to produce a bitumen with a substantially lower C_5 asphaltene content. Instead of forming a bitumen containing 10 wt% to 15 wt% n-pentane insolubles, higher severity paraffinic froth treatment conditions can be used to produce a bitumen with an n-pentane insoluble content of 2.0 wt% to 5.0 wt%. In some aspects of the modified froth treatment processes herein, the amount of n-pentane insolubles rejected by the process can correspond to 50 wt% to 90 wt% of the n-pentane insolubles in the froth.

[0033] The increased severity for the paraffinic froth treatment can be achieved using a combination of temperature, the solvent to feed weight ratio, and the type of solvent. In some aspects, the solvent to feed weight ratio can be between 1.6 : 1 and 2.5 : 1, or 1.7 : 1 and 2.2 : 1, or between 1.8 : 1 and 2.2 : 1, or between 2.0 : 1 and 2.2 : 1. Additionally or alternately, the temperature can be about 70°C to 100°C. The pressure can be roughly atmospheric (i.e., roughly 100 kPa-a). In some aspects, the solvent can be a higher severity solvent, such as using a solvent substantially containing only isopentane instead of a mixture of n-pentane and isopentane. A solvent containing substantially only isopentane has a lower solubility for nC_5 asphaltenes than a solvent that includes n-pentane. In aspects where the solvent substantially corresponds to only isopentane, a solvent to feed weight ratio between 1.9 : 1 and 2.0 : 1 can provide a similar severity to using a solvent to feed weight ratio between 2.0 : 1 to 2.2 : 1 with a roughly equal parts mixture of isopentane and n-pentane.

[0034] The resulting bitumen produced by a conventional paraffinic froth treatment process can have an API gravity of 14° or less, or 12° or less, or 10° or less, such as down to 1° or possibly still lower. In some aspects, the resulting bitumen from the conventional paraffinic froth treatment can have an API gravity of 10° or less and a kinematic viscosity at 10°C of 10,000 cSt or more.

Thermal Cracking Conditions - Visbreaking

[0035] Visbreaking is a thermal upgrading process where a feed is exposed to thermal cracking temperatures, but for a period of time where coking of the feed is reduced or minimized. Since the tendency to form coke can vary with the nature of a feed, the desired severity of a visbreaking process can vary based on the feed. In some aspects, the severity of visbreaking that can be performed without resulting in coking can be increased by adding hydrogen and/or a donor solvent to the visbreaking environment.

[0036] In most hydrocarbon processes, there is a tradeoff between reaction temperature and residence time of reactants. Because visbreaking is a well-known and widely practiced process, however, correlations have been developed so that it is possible to express precisely the severity of the visbreaking process. An expression of the "severity" of a particular visbreaking operation does not mean that a certain degree of conversion can be predicted or obtained or that a certain amount of coke or sediment will be formed; rather it means that it is possible to predict that if all other reaction parameters are unchanged (e.g., feed composition, reactor pressure) except for the temperature and residence time in the reactor, two operations can be compared and it can be determined whether one process is more severe than the other. Equations and tables have been developed for comparing reaction severities. Typical of such presentations is the discussion of "soaking factor" in Petroleum Refinery Engineering--Thermocracking and Decomposition Process--Equation 19-23 and Table 19-18, in Nelson--Modern Refining Technology, Chapter 19. The "soaking factor" corresponds to the severity index (“SI”) as defined above.

[0037] Severity index refers to the severity of the operation, expressed as the equivalent number of seconds of residence time in a reactor operating at 427°C (800°F). In very general terms, the reaction rate doubles for every 12°C to 13°C increase in temperature. Thus, 60 seconds of residence time at 427°C is equivalent to a severity index of 60, and increasing the temperature to 456°C would make the operation five times as severe, i.e. a severity index of 300. Expressed in another way, 300 seconds at 427°C is equivalent to 60 seconds at 456°C, and the same product mix and distribution should be obtained under either set of conditions.

[0038] The visbreaking process conditions which may be used can vary widely based on the nature of the heavy oil material, the optional hydrogen-donor material and other factors. In general, the visbreaking can be carried out at temperatures ranging from 350°C to 485°C, preferably 425°C to 455°C, at residence times ranging from 1 to 60 minutes, preferably 7 to 20 minutes. Expressed as severity index, the partial upgrading processes described herein can be performed at a severity index of 1500 to 4000, or 1500 to 3500, or 1500 to 2500, or 1500 to 2000.

[0039] The severity index for the visbreaking can be selected, for example, in order to achieve a desired density and/or a desired kinematic viscosity for the partially upgraded product. For example, the severity index can be selected to achieve an API gravity for the partially upgraded product of 15° or more, or 17° or more, such as up to 18°. The API gravity of the visbroken bitumen product can be greater than the API gravity of the bitumen feed by 5° or more, or 7° or more, or 9° or more, or 10° or more. For example, the API gravity of the visbroken bitumen product can be greater than the API gravity of the bitumen feed by 5° to 12°, or 7° to 12°, or 9° to 12°, or 10° to 12°. Additionally or alternately, the severity index can be selected to achieve a kinematic viscosity at 10°C of 1000 cSt or less, or 500 cSt or less, or 300 cSt or less, such as down to 150 cSt or possibly still lower. The increase in API gravity and decrease in kinematic viscosity can be achieved while producing 1.0 wt% or less coke during the visbreaking process, or 0.5 wt%, or 0.3 wt% or less, or 0.05 wt% or less, or 0.03 wt% or less, such as down to substantially no coke production. Depending on the aspect, this can correspond to performing the visbreaking at a severity index of 1500 or more, or 1800 or more, or 2500 or more, such as up to 4000 or possibly still higher. In some aspects, the level of coke production can depend on whether a subsequent process will occur after visbreaking that can reduce particulate content in the visbroken product. For example, if a trim deasphalting process is included after visbreaking, a substantial portion of any coke particles produced during visbreaking can be removed. This can allow a higher level of coke particles to be generated during visbreaking while still producing a deasphalted, visbroken product with a coke particle content of less than 0.05 wt%, or less than 0.03 wt%.

[0040] The limit of severity is determined primarily by product quality. Visbreaking is an inexpensive process, and once a visbreaker has been installed, it does not cost much more to run it at high severity in order to achieve the maximum viscosity reduction possible with a given feed stock. However, the two limiting factors in the visbreaker operation are the formation of coke (which tends to plug the coil and/or soaking drum used in the visbreaker and also take the product out of specification) and sediment (such as asphaltene) formation in the product. Sediment formation is a complicated phenomenon. As a generalization, it can be stated that, if the composition of an oil is changed enough, the asphaltic materials may no longer dissolve in the product and hence settle out as sediment. The problem becomes worse when cutter stocks or blending stocks of a less aromatic nature are added to the visbreaker product; the asphaltics or other materials that would remain dissolved in the visbreaker product are no longer soluble upon blending the visbreaker product with other, less aromatic materials.

[0041] The pressure employed in a visbreaker can usually be sufficient to maintain most of the material in the reactor coil and/or soaker drum in the liquid phase. Normally the pressure is not considered as a control variable, although attempts are made to keep the pressure high enough to maintain most of the material in the visbreaker in the liquid phase. Some vapor formation in the visbreaker is not harmful, and is frequently inevitable because of the production of some light ends in the visbreaking process. Some coil visbreaker units operate with 20-40% vaporization material at the visbreaker coil outlet. Lighter solvents will vaporize more and the vapor will not be very beneficial to improving the processing of the liquid phase material. Accordingly, liquid phase operation is preferred, but significant amounts of vaporization can be tolerated.

[0042] In general, the pressures commonly encountered in visbreakers range from 170 to 10450 kPa, or 1480 to 7000 kPa. Such pressures will usually be sufficient to maintain liquid phase conditions and the desired degree of conversion.

[0043] In some aspects, a hydrogen donor solvent can be used. In a partial upgrading environment, a suitable donor solvent can be a recycled portion of the partially upgraded effluent, such as a recycled distillate portion and/or a recycled vacuum gas oil portion. Another suitable donor solvent can be to use a synthetic crude oil, such as the partially upgraded bitumen product. If a hydrogen donor solvent is used, the hydrogen donor solvent can correspond to 0.1 wt% to 50 vol% of the combined fresh plus recycled feed flow into the visbreaker.

[0044] Additionally or alternately, a hydrogen-containing stream can be provided to the visbreaking environment. This type of visbreaking process can be referred to as hydrovisbreaking. In aspects where a hydrogen-containing stream is used, the H_2 content of the hydrogen-containing stream can be 25 vol% or more, or 50 vol% or more, such as up to substantially only H_2 (about 100 vol%). In such aspects, the visbreaking can be performed in the presence of hydrogen partial pressures ranging from 0.4 MPa-g to 13.9 MPa-g (~50 to ~2000 psig) and hydrogen treat gas rates of from 89 m^3/m^3 to 890 m^3/m^3 (~500 to ~5000 scf hydrogen/barrel of oil).

[0045] Addition of a hydrogen donor solvent and/or a hydrogen-containing stream to the reaction environment can allow a further increase in the visbreaking severity while still maintaining the amount of coke produced at 1.0 wt% or less, or 0.1 wt% or less, or 0.01 wt% or less. When using a hydrogen-containing stream and/or a hydrogen donor solvent, the amount of API gravity uplift can be 5° or more, or 7° or more, or 9° or more. For example, the amount of API gravity uplift can be 5° to 12°, or 7° to 12°, or 9° to 12°. The increased severity can be sufficient to produce a visbroken bitumen product having an API gravity of 17° or more, or 19° or more, such as up to 22° or more. Additionally or alternately, the increased severity can be sufficient to produce a visbroken bitumen product having a kinematic viscosity at 10°C of 300 cSt or less, or 150 cSt or less, or 100 cSt or less, or 50 cSt or less, such as down to 20 cSt or possibly still lower.

Example

[0046] A series of visbreaker feeds with varying levels of n-pentane insoluble content were prepared and exposed to visbreaking (thermal cracking) conditions. The visbreaker feeds were prepared based on a bitumen derived from oil sands froth. A first sample corresponded to the whole bitumen. This whole bitumen was generated using a naphtha froth treatment, so that substantially no asphaltene rejection was performed. A second sample corresponded to a bitumen prepared by performing a conventional paraffinic froth treatment on the froth. The third and fourth samples corresponded to bitumens prepared by performing a modified paraffinic froth treatment on the froth as disclosed herein, so that the third and fourth samples only contained between 2.0 wt% and 5.0 wt% n-pentane insolubles.

[0047] The four samples were exposed to visbreaking at the maximum severity that still resulted in less than 0.03 wt% coke formation. Table 1 shows the n-pentane insolubles (C_5 asphaltenes) content and the API gravity for each bitumen feed; the severity index of the visbreaking conditions; and the API gravity and kinematic viscosity at 10°C for the resulting partially upgraded bitumen. It is noted that although the severity index is expressed relative to a visbreaking temperature of 427°C, the temperatures used to generate the results in Table 1 ranges from 400°C to 435°C, with appropriate residence times to produce the severity index values listed below.

Table 1 – Visbreaking Conditions and Products

	n-pentane insolubles in feed (wt%)	API gravity of feed (@15°C)	Maximum severity before 0.03 wt% coke	Product KV@10°C and API gravity (@15°C)
Whole bitumen	17 – 20	7.0° – 7.5°	< 900	> 20,000 cSt / 10°
PFT bitumen	10.5	8.5° – 9.5°	1450	4368 cSt / 12°
Modified PFT bitumen	4.0	10.5° – 11.5°	1900	160 cSt / 16°
Modified PFT bitumen (with H-donor solvent during visbreaking)	3.4	> 12.0°	3400	40 cSt / 20°

[0048] As shown in Table 1, the severity index for maximum severity processing of the whole bitumen was less than 1000. At this severity index, the partial upgrading resulted in a product with an API gravity of 10° and a kinematic viscosity of greater than 20,000 cSt.

Additionally, the amount of API gravity uplift was limited, corresponding to less than 5° of API gravity increase relative to the feed.

[0049] For the bitumen formed by paraffinic froth treatment, the n-pentane insolubles were reduced to roughly 10 wt% of the bitumen. This allowed an increase of the maximum severity index prior to 1.0 wt% coke formation to roughly 1450. The partially upgraded product had a kinematic viscosity at 10°C of greater than 4000 cSt and an API gravity of 12°. Although this is an improvement over performing visbreaking on the whole bitumen, the properties of the partially upgraded product are still relatively far from pipeline transport specifications. Thus, substantial diluent addition would still be needed to meet such specifications. Additionally, the amount of API gravity uplift was limited, corresponding to less than 5° of API gravity increase relative to the feed.

[0050] For the third sample, using a modified paraffinic froth treatment as disclosed herein resulted in a bitumen with an n-pentane insolubles content of roughly 4.0 wt%. This additional reduction in the n-pentane insolubles content allowed for an increase in the visbreaking severity to roughly 1900 while maintaining less than 1.0 wt% of coke formation. The resulting upgraded product had an API gravity of 16° and a kinematic viscosity at 10°C of 160 cSt. Thus, the kinematic viscosity is already within a pipeline transport specification. Additionally, a reduced or minimized amount of diluent would be needed to provide the additional API gravity uplift that would be needed to achieve an API gravity of 19°. It is also noted that by allowing increased severity, an increased amount of API gravity uplift occurred. As shown in Table 1, the API gravity increase relative to the feed was roughly 5° or more.

[0051] For the fourth sample, a modified paraffinic froth treatment as disclosed herein was also used to produce a bitumen containing 3.4 wt% n-pentane insolubles. For the fourth sample, the visbreaking was performed under conditions where 15 vol% of the total feed corresponded to recycled upgraded product (i.e., an H-donor solvent). This allowed a still further increase in the visbreaking severity to roughly 3400. The resulting upgraded product had an API gravity of 20° and a kinematic viscosity at 10°C of 40 cSt. Thus, using an H-donor solvent allowed for formation of a partially upgraded product that satisfied both the kinematic viscosity and API gravity requirements for pipeline transport. Therefore, no additional diluent would be need to be added prior to transport. It is additionally noted in this example that a substantial API gravity uplift occurred, corresponding to up to 8° of API gravity increase relative to the feed.

[0052] When numerical lower limits and numerical upper limits are listed herein, ranges from any lower limit to any upper limit are contemplated. While the illustrative embodiments of the invention have been described with particularity, it will be understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the spirit and scope of the invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the examples and descriptions set forth herein but rather that the claims be construed as encompassing all the features of patentable novelty which reside in the present invention, including all features which would be treated as equivalents thereof by those skilled in the art to which the invention pertains.

[0053] The present invention has been described above with reference to numerous embodiments and specific examples. Many variations will suggest themselves to those skilled in this art in light of the above detailed description. All such obvious variations are within the full intended scope of the appended claims.

CLAIMS:

1. A method for forming a partially upgraded bitumen, comprising:

performing a paraffinic froth treatment on a feed comprising 5.0 wt% or more of particulate matter and 10 wt% or more of n-pentane insolubles to form a bitumen comprising 1.0 wt% to 8.0 wt% of n-pentane insolubles, a first API gravity, and a kinematic viscosity at 10°C of 10,000 cSt or more; and

exposing the bitumen to a thermal cracking process to form less than 0.5 wt% coke and a partially upgraded bitumen, the partially upgraded bitumen comprising:

i) an upgraded API gravity of 15° or more;

ii) an upgraded API gravity that is greater than the first API gravity by 5° or more;

iii) a kinematic viscosity at 10°C of 1000 cSt or less; or

iv) a combination of two or more of i), ii), and iii).

2. The method of claim 1, wherein the first API gravity is 14° or less.

3. The method of claim 1 or 2, wherein the partially upgraded bitumen comprises an API gravity of 17° or more.

4. The method of any one of claims 1 to 3, wherein the partially upgraded bitumen comprises a kinematic viscosity at 10°C of 500 cSt or less.

5. The method of any one of claims 1 to 4, wherein the upgraded API gravity is greater than the first API gravity by 7° or more.

6. The method of any one of claims 1 to 5, wherein the thermal cracking process comprises a severity index of 1500 or more.

7. The method of any one of claims 1 to 6, wherein the bitumen is exposed to the thermal cracking process in the presence of a hydrogen donor solvent, or wherein the thermal cracking process comprises hydrovisbreaking, or a combination thereof.

8. The method of claim 7, wherein:

a) the partially upgraded bitumen comprises an API gravity of 17° or more;

b) wherein the upgraded API gravity is greater than the first API gravity by 7° or more;

c) wherein the partially upgraded bitumen comprises a kinematic viscosity at 10°C of 300 cSt or less; or

d) a combination of two or more of a), b), and c).

9. The method of claim 7 or 8, wherein the thermal cracking process comprises a severity index of 2000 or more.

10. The method of any one of claims 1 to 9, wherein the feed comprises 15 wt% or more of n-pentane insolubles.

11. The method of any one of claims 1 to 10, wherein the bitumen comprises 0.03 wt% or less of particulate matter.

12. The method of any one of claims 1 to 11, wherein the bitumen comprises 2.0 wt% to 5.0 wt% of n-pentane insolubles.

13. The method of any one of claims 1 to 12, wherein the feed comprises 10 wt% or more of particulate matter.

14. The method of any one of claims 1 to 13, wherein performing a paraffinic froth treatment comprises exposing the feed to a C_5 to C_8 solvent at a solvent to feed weight ratio between 1.7 : 1 to 2.2 : 1 and a temperature of 70°C to 100°C.

15. The method of claim 14, wherein the solvent comprises 90 vol% or more isopentane relative to a volume of the solvent.

16. The method of claim 14, wherein the solvent to feed weight ratio is between 2.0 : 1 to 2.2 : 1.