

(57) Abrégé(suite)/Abstract(continued):

complete mixing of the solvent and the froth prior to introduction into a separation apparatus. A method of improving energy use in froth treatment includes reducing heat provided to the solvent, increasing heat provided to the froth prior to adding the solvent to reduce bitumen viscosity and adding the temperature- reduced solvent to the heated froth. A froth treatment separation process includes trim heating first and second solvent streams to adjust the first and second stage separation temperatures.

ABSTRACT

A method for pre-treating bitumen froth for mixing with solvent for froth treatment includes heating the froth to a froth-solvent mixing temperature below the solvent flash temperature and suitably high to provide reduced bitumen viscosity sufficiently low for complete mixing of the solvent and the froth prior to introduction into a separation apparatus. A method of improving energy use in froth treatment includes reducing heat provided to the solvent, increasing heat provided to the froth prior to adding the solvent to reduce bitumen viscosity and adding the temperature-reduced solvent to the heated froth. A froth treatment separation process includes trim heating first and second solvent streams to adjust the first and second stage separation temperatures.

ENHANCED TEMPERATURE CONTROL OF BITUMEN FROTH TREATMENT PROCESS

FIELD OF THE INVENTION

- 5 The present invention generally relates to the field of oil sands processing and in particular relates to the temperature control methods for enhanced treatment of bitumen froth.

BACKGROUND

- 10 Oil sand extraction processes are used to liberate and separate bitumen from oil sand so that the bitumen can be further processed to produce synthetic crude oil. Water extraction processes, such as the "Clark Hot Water Process", involves providing a conditioned oil sand aqueous slurry and then separating the slurry into fractions including an overflow bitumen froth fraction.

- 15 Bitumen froth is typically subjected to froth treatment using a solvent as diluent to remove the mineral solids and water from the froth and recover diluted bitumen. Naphthenic and paraffinic solvents have been used for this purpose. In a paraffinic froth treatment (PFT) operation, asphaltenes are precipitated along with water and mineral solids for removal from the bitumen. PFT operations thus reduce the fine solids, asphaltene and water content of the bitumen froth.

- 20 In a froth treatment operation, there may be three principal units: a froth separation unit (FSU), a solvent recovery unit (SRU) and a tailings solvent recovery unit (TSRU). In the FSU, solvent is added to the bitumen froth and the resulting mixture may be fed to a multi-stage separation process with at least two separation vessels which may be arranged in a counter-current configuration as disclosed in Canadian
25 patent application No. 2,454,942 (Hyndman et al.). The FSU produces a high diluted bitumen stream and a solvent diluted tailings stream which are respectively treated in the SRU and TSRU to recover solvent for reuse in the FSU.

- Some control methods and operational conditions have been proposed in an attempt to improve the separation performance or operational efficiency of froth
30 treatment operations. Hyndman et al. discloses operating an FSU between 70°C and 90°C. It is also known to provide heat exchangers for generally heating or

cooling various streams associated with a PFT operation or for keeping overall units within a particular temperature range. Hyndman et al. also discloses a temperature control technique for a two-stage counter-current FSU. In the two-stage counter-current FSU, there is a first stage settler which is fed diluted froth and produces
5 overflow and underflow components. Fresh solvent is added to the first stage underflow and the resulting stream is fed to a second stage settler which produces a second stage overflow with high solvent content and an underflow of solvent diluted tailings. The second stage overflow is recycled and added into the bitumen froth to produce the first stage diluted froth. Hyndman et al. discloses that by controlling the
10 temperature of solvent added to the first stage underflow, operating temperatures of the first stage settler can be indirectly regulated.

Known techniques for handling temperature and controlling separation performance in froth treatment operations, in particular in the FSU, have had several drawbacks.

Some research identifies that temperature in general influences paraffinic solvent
15 assisted treatment of bitumen froth. One paper entitled "*Structure of water/solids/asphaltenes aggregates and effect of mixing temperature on settling rate in solvent-diluted bitumen*" Long et al., Fuel Vol. 83, 2004 (hereafter referred to as "Long et al.") identifies that in paraffinic solvent assisted froth treatment, temperature influences water/solids/precipitated-asphaltene aggregate structures
20 and settling of the aggregates. In Long et al., bitumen froth and paraffinic solvent were combined and the mixture was heated to desired temperatures between 30°C and 120°C, allowed to cool to 30°C followed by settling.

Bitumen froth quality can range significantly, for instance from 50 wt% to 70 wt% bitumen. In addition, the main components of the froth, which are bitumen, water
25 and minerals, differ significantly in heat capacity. These differences of physical properties can result in variable operating temperatures when the main components are blended with solvent at specific temperature conditions. Since the performance of the separation is temperature sensitive, varying compositions and temperatures translates to varying process performance.

30 In summary, known practices and techniques for the separation treatment of bitumen froth experience various drawbacks and inefficiencies, and there is indeed a need for a technology that overcomes at least some of those drawbacks and inefficiencies.

SUMMARY OF THE INVENTION

The present invention responds to the above-mentioned need by providing methods and processes for temperature enhanced froth treatment.

More particularly, one embodiment the invention provides a method for pre-treating
5 bitumen containing froth for mixing with a solvent containing stream to produce a diluted froth for introduction into a separation apparatus for separation into a diluted bitumen component and a solvent diluted tailings component, the method comprising heating the bitumen froth to produce a heated froth with a froth-solvent mixing temperature that is below a flash temperature of the solvent and suitably high to
10 provide a reduced bitumen viscosity sufficiently low to allow complete mixing of the solvent and the froth so that the diluted froth is fully mixed prior to introduction thereof into the separation apparatus.

In an optional aspect, the bitumen froth has a bitumen content between about 40 wt% and about 75 wt%.

15 In another optional aspect, the method includes adapting the heating of the bitumen froth in accordance with the bitumen content thereof.

In another optional aspect, the solvent is selected from paraffinic solvent and naphthenic solvent.

In another optional aspect, the heating is conducted by direct steam injection.

20 In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above about 60°C. In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above about 70°C. In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above about 90°C. In another optional aspect, the heating is conducted
25 to control the froth-solvent mixing temperature in between about 90°C and about 120°C.

In another optional aspect, the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} of at most about 100 μm .

In another optional aspect, the heating is conducted to cause formation of bitumen
30 droplets having a maximum droplet size d_{\max} in between about 100 μm and about 25 μm .

In another optional aspect, the heating is conducted to control the reduced bitumen viscosity of at most about 650 cP. In another optional aspect, the heating is conducted to control the reduced bitumen viscosity in between about 100 cP and about 650 cP. In another optional aspect, the heating is conducted to provide the
5 reduced bitumen viscosity between about 1.5 times and about 100 times lower than the viscosity of the bitumen in the froth.

In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature at least about 10°C below the flash temperature of the solvent.

In another optional aspect, the heating is conducted to reduce a bitumen/solvent
10 viscosity ratio by at least about an order of magnitude.

In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above a temperature of the solvent, for instance at least about 10°C above the temperature of the solvent.

In another optional aspect, the separation apparatus comprises a first stage
15 separation vessel and a second stage separation vessel in counter-current configuration. The method may include supplying the diluted froth to the first stage separation vessel and producing the diluted bitumen component and a first stage underflow component; adding a make-up solvent stream to the first stage underflow component to produce a diluted first stage underflow; supplying the diluted first
20 stage underflow to the second stage separation vessel and producing the a second stage overflow component and a second stage underflow component as the solvent diluted tailings component; and supplying the second stage overflow component as the solvent containing stream added to the heated froth.

In another optional aspect, the method includes trim heating the solvent containing
25 stream to control temperatures of the diluted froth and the first stage separation vessel.

In another optional aspect, the method includes trim heating the make-up solvent stream to control temperatures of the diluted first stage underflow to the second stage separation vessel.

30 In another optional aspect, the method includes maintaining a first operating temperature of the first stage separation vessel above a second operating temperature of the second stage separation vessel.

In another optional aspect, the method includes providing the make-up solvent stream cooler than the solvent containing stream added to the heated froth.

In another optional aspect, the method includes subjecting the solvent diluted tailings component to solvent recovery flashing and operating the second stage separation vessel such that the solvent diluted tailings component has a temperature suitable for the solvent recovery flashing.

In another embodiment, there is provided a method for pre-treating bitumen containing froth for mixing with a paraffinic solvent containing stream to produce a diluted froth for introduction into a separation apparatus for separation into a diluted bitumen component and a solvent diluted tailings component, the method comprising heating the bitumen froth to produce a heated froth with a reduced viscosity and a froth-solvent mixing temperature that is below a flash temperature of the solvent and ranging from about 75°C to about 95°C, the heated bitumen froth viscosity being at most about 700 cP higher than a solvent stream viscosity.

In an optional aspect, the bitumen froth has a bitumen content between about 40 wt% and about 75 wt%.

In another optional aspect, the method includes adapting the heating of the bitumen froth in accordance with the bitumen content thereof.

In another optional aspect, the heating is conducted by direct steam injection.

In another optional aspect, the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} of at most about 100 μm .

In another optional aspect, the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} in between about 100 μm and about 25 μm .

In another optional aspect, the heating is conducted to control the reduced bitumen viscosity of at most about 650 cP.

In another optional aspect, the heating is conducted to control the reduced bitumen viscosity in between about 100 cP and about 650 cP.

In another optional aspect, the heating is conducted to provide the reduced bitumen viscosity between about 1.5 times and about 100 times lower than the viscosity of the bitumen in the froth.

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In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature at least about 10°C below the flash temperature of the solvent.

In another optional aspect, the heating is conducted to reduce a bitumen/solvent viscosity ratio by at least about an order of magnitude.

- 5 In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above a temperature of the solvent.

In another optional aspect, the froth-solvent mixing temperature is at least about 10°C above the temperature of the solvent.

- 10 In another optional aspect, the separation apparatus comprises a first stage separation vessel and a second stage separation vessel in counter-current configuration.

- 15 In another optional aspect, the method may include supplying the diluted froth to the first stage separation vessel and producing the diluted bitumen component and a first stage underflow component; adding a make-up solvent stream to the first stage underflow component to produce a diluted first stage underflow; supplying the diluted first stage underflow to the second stage separation vessel and producing a second stage overflow component and a second stage underflow component as the solvent diluted tailings component; and supplying the second stage overflow component as the solvent containing stream added to the heated froth.

- 20 In another optional aspect, the method includes trim heating the solvent containing stream to control temperatures of the diluted froth and the first stage separation vessel.

- 25 In another optional aspect, the method includes trim heating the make-up solvent stream to control temperatures of the diluted first stage underflow to the second stage separation vessel.

In another optional aspect, the method includes maintaining a first operating temperature of the first stage separation vessel above a second operating temperature of the second stage separation vessel.

- 30 In another optional aspect, the method includes providing the make-up solvent stream cooler than the solvent containing stream added to the heated froth.

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In another optional aspect, the method includes subjecting the solvent diluted tailings component to solvent recovery flashing and operating the second stage separation vessel such that the solvent diluted tailings component has a temperature suitable for the solvent recovery flashing.

- 5 In another embodiment, the present invention provides a method of improving energy use in a froth treatment operation, the froth treatment operation comprising adding a solvent containing stream to bitumen froth to produce a diluted froth, introducing the diluted froth into a separation apparatus and producing from the separation apparatus a diluted bitumen component and a solvent diluted tailings
- 10 component, the method comprising: reducing heat provided to the solvent containing stream thereby producing a temperature-reduced solvent stream; increasing heat provided to the bitumen froth prior to adding the solvent containing stream thereto to produce a heated froth with a froth-solvent mixing temperature that is below a flash temperature of the solvent and suitably high to provide a reduced
- 15 bitumen viscosity; and adding the temperature-reduced solvent to the heated froth and thereby producing the diluted froth for separation.

This method may have one or more of the optional aspects mentioned herein-above.

- In another embodiment, there is provided a method of improving energy use in a
- 20 froth treatment operation, the froth treatment operation comprising adding a paraffinic solvent containing stream to bitumen froth to produce a diluted froth, introducing the diluted froth into a separation apparatus and producing from the separation apparatus a diluted bitumen component and a solvent diluted tailings component, the method comprising: reducing heat provided to the solvent
- 25 containing stream thereby producing a temperature-reduced solvent stream; increasing heat provided to the bitumen froth prior to adding the solvent containing stream thereto to produce a heated froth with a froth-solvent mixing temperature that is below a flash temperature of the solvent and suitably high to provide a reduced bitumen viscosity; and adding the temperature-reduced solvent to the heated froth
- 30 and thereby producing the diluted froth for separation.

In an optional aspect, the bitumen froth has a bitumen content between about 40 wt% and about 75 wt%.

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In another optional aspect, the method includes adapting the heating of the bitumen froth in accordance with the bitumen content thereof.

In another optional aspect, the heating is conducted by direct steam injection.

5 In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above about 60°C.

In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above about 70°C.

In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above about 90°C.

10 In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature in between about 90°C and about 120°C.

In another optional aspect, the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} of at most about 100 μm .

15 In another optional aspect, the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} in between about 100 μm and about 25 μm .

In another optional aspect, the heating is conducted to control the reduced bitumen viscosity of at most about 650 cP.

20 In another optional aspect, the heating is conducted to control the reduced bitumen viscosity in between about 100 cP and about 650 cP.

In another optional aspect, the heating is conducted to provide the reduced bitumen viscosity between about 1.5 times and about 100 times lower than the viscosity of the bitumen in the froth.

25 In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature at least about 10°C below the flash temperature of the solvent.

In another optional aspect, the heating is conducted to reduce a bitumen/solvent viscosity ratio by at least about an order of magnitude.

In another optional aspect, the heating is conducted to control the froth-solvent mixing temperature above a temperature of the solvent.

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In another optional aspect, the froth-solvent mixing temperature is at least about 10°C above the temperature of the solvent.

In another optional aspect, the separation apparatus comprises a first stage separation vessel and a second stage separation vessel in counter-current
5 configuration.

In another optional aspect, the method includes supplying the diluted froth to the first stage separation vessel and producing the diluted bitumen component and a first stage underflow component; adding a make-up solvent stream to the first stage underflow component to produce a diluted first stage underflow; supplying the
10 diluted first stage underflow to the second stage separation vessel and producing a second stage overflow component and a second stage underflow component as the solvent diluted tailings component; and supplying the second stage overflow component as the solvent containing stream added to the heated froth.

In another optional aspect, the method includes trim heating the solvent containing
15 stream to control temperatures of the diluted froth and the first stage separation vessel.

In another optional aspect, the method includes trim heating the make-up solvent stream to control temperatures of the diluted first stage underflow to the second stage separation vessel..

20 In another optional aspect, the method includes maintaining a first operating temperature of the first stage separation vessel above a second operating temperature of the second stage separation vessel.

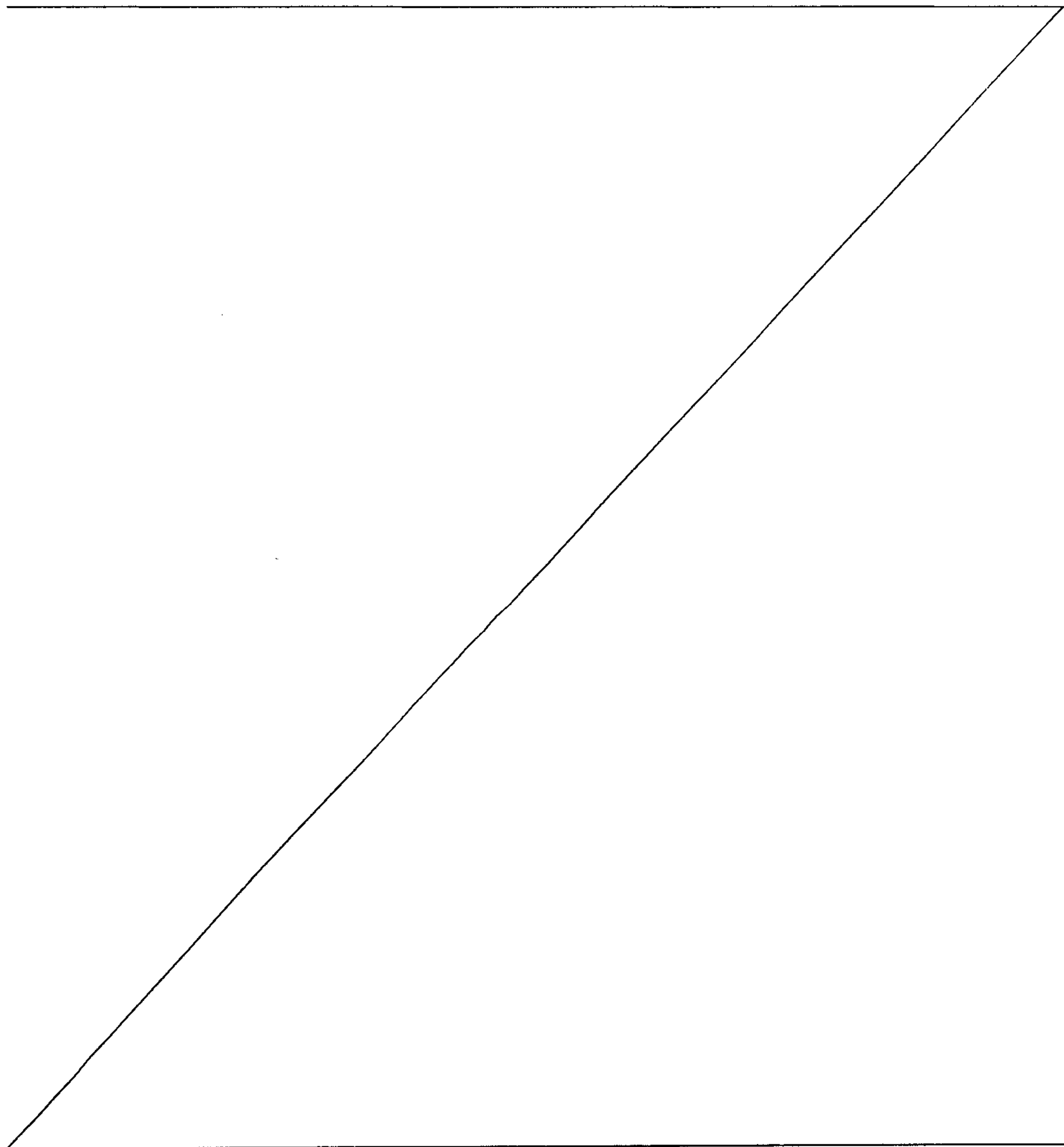
In another optional aspect, the method includes providing the make-up solvent stream cooler than the solvent containing stream added to the heated froth.

25 In another optional aspect, the method includes subjecting the solvent diluted tailings component to solvent recovery flashing and operating the second stage separation vessel such that the solvent diluted tailings component has a temperature suitable for the solvent recovery flashing.

In another embodiment, the present invention provides a process for separating a
30 bitumen froth into a diluted bitumen component and a diluted tailings component, the process comprising: adding a first solvent containing stream to the bitumen froth

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to produce a diluted bitumen froth, the first solvent-containing stream having a first solvent temperature and the bitumen froth having a froth temperature; separating the diluted bitumen froth into a first stage overflow component and a first stage underflow component having an underflow temperature, wherein the first stage overflow component comprises the diluted bitumen component; adding a second solvent containing stream to the first stage underflow component to produce a diluted first stage underflow component, the second solvent containing stream having a second solvent temperature; separating the diluted first stage underflow component into a second stage overflow component and a second stage underflow component, wherein the second stage underflow component comprises the diluted



tailings component; trim heating the first solvent containing stream to adjust the first solvent temperature to maintain consistent first stage separation temperature; and trim heating the second solvent containing stream to adjust the second solvent temperature to maintain consistent second stage separation temperature.

- 5 This process may have one or more of the optional aspects of the methods mentioned herein-above. In one optional aspect of the process, the froth temperature is at least 65°C, between about 70°C and about 120°C, or above 90°C. In another optional aspect of the process, the first stage separation temperature is maintained above the second stage separation temperature. The bitumen froth may
10 be preheated before the adding of the first solvent containing stream to the bitumen froth. In another optional aspect of the process, the trim heating of the first and second solvent containing streams are performed with heat exchangers. In further optional aspects of the process, the solvent may be naphthenic or paraffinic solvent.

BRIEF DESCRIPTION OF THE DRAWINGS

- 15 Fig 1 is a schematic flow diagram according to an embodiment of the present invention.

Fig 2 is a schematic flow diagram according to an embodiment of the present invention.

- Fig 3 is a schematic flow diagram according to another embodiment of the present
20 invention.

Fig 4 is a graph of bitumen density versus temperature.

Fig 5 is a graph of the natural logarithm of viscosity versus temperature of bitumen.

DETAILED DESCRIPTION

- In one embodiment of the present invention, the bitumen froth is heated to a froth
25 mixing temperature that is below the flash temperature of the solvent and suitably high to reduce the viscosity of the bitumen froth to a froth mixing viscosity sufficiently low to allow complete mixing of the solvent and the bitumen froth to form a fully mixed diluted froth prior to its introduction into the separation vessel. Controlling the temperature of the bitumen froth stream, rather than merely the solvent addition
30 stream, the combined diluted froth stream or the separation vessel, allows improved mixing control and results.

Bitumen froth has a composition ranging between about 50 wt% to about 70 wt% bitumen with the remainder comprising mostly water and mineral solids. The initial bitumen viscosity in froth is often in the range of about 1,000 to about 10,000 centipoise (cP). In contrast, the viscosity of the solvent stream added to the bitumen
5 froth is between about 0.1 and about 1 cP, often around 0.2 cP. Adjusting the solvent temperature thus has a negligible effect on mixing and formation of a properly blended diluted froth. In this regard, it is noted that solvent temperature can have effects on the performance of other process steps, which will be further discussed herein-below. As for the step of mixing the solvent and the bitumen froth,
10 the stream that limits mixing efficacy is the bitumen froth. By controlling the temperature of the bitumen froth as high as possible without exceeding the flash temperature of the solvent, the bitumen froth is rendered susceptible to breaking up into droplets having a sufficiently small diameter to ensure dissolution and reactions with the added solvent and thus the mixing efficacy is enhanced.

15 In one aspect, the froth mixing temperature is controlled sufficiently low such that the mixing with the solvent in the in-line supply system to the separation vessel achieves a fully mixed diluted froth at the discharge into the separation vessel. The in-line supply system may include one or more mixer, piping including pipe lengths and fittings, valves and other in-line devices or arrangements that may impart mixing
20 energy to the blending diluted bitumen. The froth mixing temperature may be tailored to a given in-line supply system and the other operating conditions such as pressure and flow rate. The froth mixing temperature may also be controlled to vary depending on the bitumen froth composition to achieve the froth mixing viscosity required to achieve the blending in a given in-line supply system. It should thus be
25 understood that FSUs and processes may be adjusted or retrofitted to allow froth mixing temperature control based on existing in-line supply systems. The retrofitting may include addition of froth heaters and temperature control system upstream of the solvent addition point.

In another embodiment of the present invention, the solvent containing streams
30 added to the bitumen containing streams are trim heated to maintain consistent temperature in the first and second stage separation vessels. Maintenance of consistent temperatures in the separation vessels allows improved process control and bitumen recovery over variable froth flows and feed compositions.

Embodiments of the present invention will further be described and elaborated in connection with Fig 1.

Fig 1 illustrates an FSU 10 according to an embodiment of the present invention. The FSU 10 is preferably operated in connection with embodiments of the process of the present invention for treating and separating bitumen froth. It should be noted that the bitumen froth treatment process may be paraffinic or naphthenic or may use other mixtures or types of solvents.

The FSU 10 receives bitumen froth 12 from an upstream separation vessel (not illustrated) via pipeline. The bitumen froth 12 may contain a range of bitumen content from about 50 wt% to about 70 wt% with an average of about 60 wt%, for example, and may be measured and characterized to assess a number of variables which may include flow rate, composition, viscosity, density and initial froth temperature which may be used to estimate or calculate additional variables such as heat capacity. One or more measurement devices 14 may be used to ascertain properties of the bitumen froth 12.

In the temperature control scheme for controlling the temperature of the bitumen froth 12, a heater 16 is preferably provided. The heater 16 may include multiple heater sub-units (not illustrated) and is preferably a direct steam injection (DSI) type heater which injects steam 18 directly into the bitumen froth 12 to produce a heated bitumen froth 20. A temperature measurement and control system 22 may be provided for controlling the temperature of the heated bitumen froth 20.

The heater 16 and associated heating step may be provided and operated as described in Canadian patent application No. 2,735,311 (van der Merwe et al.). The heating step for heating bitumen froth with varying heating requirement, may include (a) injecting steam directly into the froth at a steam pressure through a plurality of nozzles, wherein the injecting of the steam and the size and configuration of the nozzles are provided to achieve sonic steam flow; (b) operating the plurality of the nozzles to vary steam injection by varying a number of the nozzles through which the injecting of the steam occurs in response to the variable heating requirements for the froth; and (c) subjecting the froth to backpressure sufficient to enable sub-cooling relative to the boiling point of water.

In one aspect, the heated bitumen froth 20 is supplied to a froth tank 24. Alternatively, the heated bitumen froth 20 may be supplied directly to downstream units. The heated froth 20 is pumped via a froth tank pump 26 toward solvent addition point 28 and mixer 30. The solvent addition point 28 may be part of the mixer 30 or may be immediately upstream of a separate mixer 30. The solvent addition point may be, for example, a pipeline junction such as a tee junction, a co-annular mixing device, or another type of arrangement. A solvent containing stream 32 is thus added to the heated bitumen froth 20 at the solvent addition point 28. Thus, the heated bitumen froth 20 is heated and then mixed with a first solvent-containing stream 32 breaking the bitumen froth into droplets and ensuring mass and heat transfer with the first solvent-containing stream 32. While froth may macroscopically appear to be a homogeneous mixture, at close range the froth fluid comprises discrete droplets, parcels and particles of material. Breaking up the discrete droplets facilitates the hydrocarbons to dissolve. The solvent addition and mixing produce a diluted bitumen froth 34.

The mixer 30 and associated mixing step may be provided and operated as described in Canadian patent application No. 2,733,862 (van der Merwe et al.). The step of adding and mixing solvent with the bitumen froth may include addition, mixing and conditioning performed with particular CoV, Camp number, co-annular pipeline reactor where the solvent is added along the pipe walls, and/or pipe wall contact of lower viscosity fluid.

The diluted bitumen froth 34 is supplied to a first stage separation vessel 36 via a discharge 38 which may extend and be located within the first stage separation vessel 36. It is noted that the solvent and bitumen froth blend and form the diluted bitumen froth 34 within what is referred to herein as an in-line supply system 40, which includes the mixer 30 and all piping, fittings, and in-line devices from the solvent addition point 28 to the discharge 38. The in-line supply system 40 imparts a mixing energy to the blending solvent and froth mixture. In one aspect, the froth temperature controller 22 is managed, operated, designed, calibrated, adjusted to pre-determined to tailor the heating imparted to the bitumen froth 12 so that the temperature of the heated bitumen froth 20 enables a sufficiently low viscosity so that the mixing energy of the in-line supply system 40 is sufficient to produce a fully mixed diluted bitumen froth at least at the discharge 30 into the first stage separation

vessel 36. In another preferred aspect, the froth temperature controller 22 tailors the heating so that the temperature of the heated bitumen froth 20 enables a sufficiently low viscosity so that the initial rapid mixing in the given mixer 30 is sufficient to produce a fully mixed diluted bitumen froth flowing out of the mixer 30. The
5 temperature controller 22 may also be coupled and receive information from the measurement devices 14 to adjust the heater 16. For example, the measurement devices 14 may monitor the bitumen content of the froth 12 and the heating may be adjusted to achieve the desired temperature and viscosity in relation to the bitumen content.

10 In this regard, the heating, mixing and conditioning are coordinated to obtain the diluted froth. Considering the kinetics of mixing the solvent into the bitumen froth, the froth is heated sufficiently such that in the in-line supply system provides sufficient time and conditioning energy to produce the fully mixed diluted bitumen froth at the solvent-bitumen system kinetics. Sufficiently increasing the temperature of the froth
15 causes a viscosity reduction allowing reduced pipeline length and mixing equipment and improving efficiency and performance of control options.

The supplying of the diluted bitumen froth 34 to the separation vessel may also be performed as described in Canadian patent application No. 2,733,862 (van der Merwe et al.). The diluted bitumen froth 34 may be supplied to the vessel with axi-
20 symmetric phase and velocity distribution and/or particular mixing and conditioning features such as flow diffusing and/or flow straightening.

Still referring to Fig 1, the first stage separation vessel 36 produces a first stage overflow component 42 consisting of diluted bitumen and a first stage underflow component 44 consisting of first stage tailings containing water, mineral solids,
25 residual bitumen and, in paraffinic treatment processes, precipitated asphaltenes in water/solids/precipitated-asphaltene aggregates. The first stage overflow component 42 is pumped via first stage overflow pump 46 for further downstream processing as high diluted bitumen 48. Here it is noted that a portion of the first stage overflow component may be withdrawn as a diltbit recirculation stream 50 for recirculation
30 upstream of the first stage separation vessel 36. For instance, the diltbit recirculation stream 50 may be reintroduced into the bitumen froth 12, the heated bitumen froth 20 upstream or downstream of the froth tank 24 or froth tank pump 26, or the diluted bitumen froth 34, depending on operating parameters and desired effect. In one

preferred aspect, the dilbit recirculation stream 50 is reintroduced into the heated bitumen froth 20 in between the froth pump 26 and the mixer 30.

The first stage underflow component 44 is pumped via first stage underflow pump 52 toward a second stage. In the second stage, the first stage underflow component 44
5 is combined with a second solvent-containing stream 54. The second solvent-containing stream 54 preferably consists essentially of solvent which has been recovered from the SRU and TSRU and also includes fresh make-up solvent. This stream is provided as an unheated solvent stream 56 which is preferably heated in a second stage solvent trim heater 58, which may be a heat exchanger receiving
10 steam S and releasing condensate C. The resulting heated second solvent containing stream 54 is added to the first stage underflow component 44 at a second solvent addition point 60. Like the first addition point 40, the second solvent addition point 60 may be located and arranged in various configurations relative to the other elements of the second stage. A second stage mixer 62 is preferably provided
15 immediately downstream of the second solvent addition point 60. Downstream of the mixer a diluted first stage underflow 64 is supplied to a second stage separation vessel 66 which produces a second stage underflow component 68 which is sent via froth treatment tailings pump 70 to the TSRU as solvent diluted tailings. The second stage separation vessel 66 also produces a second stage overflow component 72
20 which is pumped via second stage overflow pump 74.

As illustrated, the second stage overflow component 72 contains a significant amount of solvent and is preferably used as the first solvent containing stream 32. The second stage overflow component 72 is withdrawn from the second stage separation vessel 66 at the separation temperature and is preferably heated by a
25 first stage solvent trim heater 76.

In one optional aspect, the solvent trim heaters 58, 76 are regulated to heat the solvent containing streams to a desired temperature to maintain a consistent temperature of the diluted first stage underflow and diluted bitumen froth streams. Thus, trim heating temperature controllers 78, 80 may be used to monitor the
30 temperature of the diluted streams 64, 34 and adjust the trim heating of the solvent accordingly. By providing consistent temperatures for the diluted streams 34, 64 feeding the first and second separation vessels 36, 66, the settling temperature and

conditions can be advantageously controlled resulting in improved setting stability and performance.

Referring to Fig 2, the following legend is presented and will be further discussed herein-below:

- 5 T_{Fi} initial froth temperature
- S steam
- C condensate
- T_{Fh} heated froth temperature
- T_{OFSh} heated solvent containing overflow stream temperature
- 10 T_{FS} initial froth-solvent temperature
- T_{DF} diluted bitumen froth temperature
- T_{SEP1} first stage separation vessel temperature
- T_{OF1} first stage overflow component temperature
- T_{UF1} first stage underflow component temperature
- 15 T_{FSh} heated fresh solvent temperature
- T_{FSi} initial fresh solvent temperature
- T_{UFS} initial underflow-solvent temperature
- T_{DUF} diluted underflow temperature
- T_{SEP2} second stage separation vessel temperature
- 20 T_{UF2} second stage underflow temperature
- T_{REC} dilbit recirculation stream temperature
- T_{OFSi} initial second stage overflow temperature

In one embodiment of the present invention, the FSU temperature control method includes heating the froth to a froth mixing temperature that is below the flash
 25 temperature of the solvent and suitably high for adequate viscosity reduction increase the froth droplet surface area and thus the mixing, breaking and dissolution of the froth droplets with the added solvent.

Since bitumen froth and solvent systems have particular and challenging flow, mixing and reaction characteristics, this temperature control methods of the present invention allow improved control and performance of both mixing and downstream separation performance. For instance, in a paraffinic froth treatment process, if the bitumen froth is at an inadequately high viscosity when paraffinic solvent is added, there are a number of inconveniences. First, due to the high viscosity of the froth, the solvent will have difficulty mixing throughout the froth volume, increasing the occurrence of unmixed parcels of bitumen upon introduction into the separation vessel and thus decreasing the bitumen recovery, decreasing the asphaltene precipitation and increasing solvent consumption due to inefficient use of the added solvent. Second, due to the high viscosity of the froth, the solvent will mix more gradually into the froth, causing more gradual formation of water/solids/precipitated-asphaltene aggregates at different times prior to introduction into the separation vessel, which can result in a non-uniform composition and variable aggregate structures distributed throughout the diluted froth feed causing unstable and decreased settling performance. Third, if the temperature control scheme for the FSU involves heating only the solvent stream or the solvent added froth stream or simply maintaining the separation vessels at a desired temperature, the benefits of initial rapid mixing of bitumen froth and solvent are diminished.

In addition, a PFT process may be designed to minimize solvent use and the conditions may be such that the optimum solvent-to-bitumen ratio (S/B) is between about 1.4 and about 2.0, preferably between about 1.6 and about 1.8. In the case of relatively low S/B, there is an increased importance of reducing and controlling the bitumen viscosity due to the relatively high content of the higher viscosity bitumen, i.e. bitumen, in the froth-solvent mixing.

In one optional aspect, the froth mixing temperature is controlled so as to be sufficiently high to form bitumen droplets having a maximum droplet size d_{\max} of about 100 μm . The d_{\max} is preferably in between about 100 μm and about 25 μm .

For a paraffinic froth treatment process, the froth mixing temperature in most cases is preferably above 60°C. The froth mixing temperature T_{Fh} may be above 70°C, 90°C, about 100°C, above 110°C and up to 120°C for some cases.

The froth mixing temperature is preferably controlled to provide a bitumen viscosity between about 650 cP and about 100 cP.

In another aspect, the heating is performed such that the froth and first solvent containing streams have viscosities as close as possible to each other. For instance, the froth may be heated so that the difference in viscosity between the bitumen and the solvent addition stream is between about 100 cP and about 700 cP. The froth heating may be performed to achieve heated bitumen viscosity of at most about 700 cP higher than the solvent stream viscosity, preferably at most about 200 cP higher, still preferably at most about 150 cP higher.

In another embodiment, the solvent containing streams are trim heated to control the feed temperatures into the first and second stage separation vessels. Due to fluctuating bitumen froth qualities, achieving a consistent temperature of the diluted bitumen froth stream fed into the first stage separation vessel is challenging. By trim heating the second stage overflow stream 72 to produce a trim heated solvent containing stream 32, the diluted froth temperature can be maintained and, in turn, the first stage separation vessel 36 can be operated at a consistent stable temperature. The first stage underflow 44 as also combined with solvent and by trim heating the fresh solvent 56 to produce a trim heated second solvent containing stream 54, the diluted froth temperature can be maintained and, in turn, the second stage separation vessel 66 can be operated at a second consistent stable temperature. For instance, the first stage separation vessel 36 may be operated at a higher temperature, such as about 90°C and the diluted froth 34 can be maintained at this temperature; and the second stage separation vessel 66 may be operated at a lower temperature, such as about 80°C, thereby reducing the heat requirements of the second trim heater 58 to maintain the second stage diluted feed stream 64 at about 80°C. Thus, the trim heating aspect of the temperature control strategy utilizes a balanced approach of trim heating both the first and second solvent containing streams and also trim heats the first solvent containing stream to a higher temperature for addition into the bitumen compared to the temperature of the second solvent containing stream. This provides improved separation performance and stability of the FSU 10 operation.

In one optional aspect, the solvent addition temperatures T_{OFSh} and T_{FSh} are adjusted according to the quality of the respective bitumen froth and first stage underflow component streams. This temperature adjustment is made in order to obtain

enhanced mixing and maintain a constant temperature for both the diluted bitumen froth and the diluted first stage underflow component fed to the separation vessels.

The trim heating may be performed with a direct in-line addition of a heat source or with indirect contact with a heat source through a heat exchanger. Preferably, the trim heating is performed in heat exchangers using steam to trim heat the solvent and producing condensate.

In one aspect, the trim heating is performed such that the second solvent temperature T_{FSH} is controlled above 50°C, preferably between about 60°C and about 100°C. The second solvent temperature T_{FSH} may also be controlled in such a way that the diluted first stage underflow component 64 has a viscosity between about 50 cP and about 650 cP.

In another aspect, the extent of trim heating depends on the second stage separating vessel temperature, the first stage underflow component quality and the source of the solvent. Bitumen froth quality often ranges from 50 wt% to 70 wt% of bitumen and the key components which are bitumen, water and mineral differ significantly in heat capacity. The adjustment of the first solvent temperature T_{OFSh} and second solvent temperature T_{FSH} may be particularly controlled in accordance with the compositions of the froth or first stage underflow to achieve stable temperature, viscosity and density characteristics of the diluted streams in order to enhance the settling of asphaltene precipitates and aggregates. The simultaneous control of the temperature before both the first stage separation and the second stage separation also ensures enhanced stability and separation performance of the froth treatment, which is also beneficial for downstream unit operations, such as solvent recovery operation and tailings solvent recovery operation.

Referring to Figs 1 and 2, there is one corresponding solvent containing stream with temperatures T_{OFSh} and T_{FSH} for addition into each process stream 20 and 44. The temperature of the heated bitumen froth 20 can thus be controlled so as to achieve adequate mixing with a single addition point of the solvent containing stream 32.

Referring to Fig 3, the FSU may include multiple addition points of two solvent containing streams 32a and 32b into the bitumen froth and may also have an additional stream that is combined with the bitumen froth prior to the first stage separation vessel 36. More particularly, a first solvent stream 32a may be added to

the heated bitumen froth 20a and the resulting partially diluted bitumen froth 34a may be subjected to mixing in mixer 30a. Next, a second solvent stream 32b may be added to the partially diluted bitumen froth 34a and the resulting froth-solvent stream 34b may be subjected to mixing in second mixer 30b to ultimately produce the

5 diluted froth 34 for introduction into the first stage separation vessel 36. Preferably, the first solvent stream 32a is added in an amount to provide an S/B in the partially diluted bitumen froth 34a below the asphaltene precipitation threshold thereby largely avoiding formation of water/solids/precipitated-asphaltene aggregates in the partially diluted bitumen froth 34a which has thoroughly mixed solvent throughout. The first

10 solvent stream 32a flow is thus controlled in accordance with the bitumen content of the heated froth 20a to ensure a controlled S/B. The second solvent stream 32b is then added in an amount to exceed the asphaltene precipitation threshold and thus induce asphaltene precipitation and formation of water/solids/precipitated-asphaltene aggregates in the second froth-solvent stream 34b and the fully mixed diluted froth

15 feed stream 34. In addition to multiple staged addition of solvent, the FSU may also include another bitumen containing stream added into the bitumen froth to help heat and/or reduce the viscosity of the bitumen froth prior to the addition of solvent. In one aspect, the additional bitumen containing stream may be the diltbit recirculation stream 50. This diltbit recirculation stream 50 may be added to the bitumen froth

20 before or after heating in heater 16. The dilbit-froth mixture may be subjected to mixing in an additional mixer 82 to produce heated bitumen froth stream 20a. However, it should be noted that the initial heating and temperature control of the bitumen froth enables advantageous mixing with any subsequent stream including viscosity reducing streams, e.g. stream 50, and solvent containing streams, e.g.

25 streams 32a and 32b, facilitating stable and well-performing separation.

In one preferred aspect, the first solvent-containing stream 32 comprises at least a portion of the second stage overflow component 72. As illustrated in Fig 1, the second stage overflow component 72 may be completely recycled and heated to form the first solvent-containing stream 32. In this configuration, the operating

30 temperatures of the first stage separation and the second stage separation interact. Due to retention volumes in the separating vessels 36, 66, this interaction is delayed and permits gradual temperature adjustments over time. The first solvent temperature T_{OFSh} and second solvent temperature T_{FSh} are preferably each controlled with a variation of $\pm 2^{\circ}\text{C}$. The second solvent-containing stream 54 may

be essentially solvent such as a recycled solvent coming from upstream or downstream operations, preferably from a SRU and a TSRU. In one aspect, the intent of the solvent trim heaters 58, 76 is to minimize temperature variations in the vessels 36, 66 for promoting operational stability and separation performance of the whole process. Indeed, the gravity separation of components in the vessels 36, 66 depends on both density and viscosity differentials which are affected by temperature.

In another optional aspect, avoiding undesirable temperature variations in the first stage separating vessel 36 and the second stage separating vessel 66 may include controlling the bitumen froth temperature T_{Fh} higher than the first solvent temperature T_{OFSh} . In fact, in one aspect, to achieve the same diluted froth temperature T_{DF} , it is preferable to devote the heating energy to the bitumen froth to obtain a hotter heated bitumen froth than to the first solvent containing stream 32. This heating methodology provides improved utilization of heat energy by reducing the viscosity of the bitumen for better mixing with the same feed temperature outcome, which translates into improved settling stability and performance and efficient utilization of solvent.

In another aspect, the heated froth temperature T_{Fh} is at least 70°C and more preferably ranges between about 75°C and 95°C. Furthermore, the addition of solvent under controlled temperature also helps to ensure maximum mixing with the bitumen froth. In another aspect, the difference between the heated froth temperature T_{Fh} and the first solvent containing temperature T_{OFSh} may be controlled between about 2°C and 20°C with $T_{Fh} > T_{OFSh}$.

In a further optional aspect, the second stage separating vessel 66 has an operating temperature lower than that of the first stage separating vessel 36, i.e. $T_{SEP1} > T_{SEP2}$. In this aspect, higher temperatures are viewed as less important in the second stage separation vessel partly since separation parameters due the high S/B are easier to achieve in the second stage than the first.

In another aspect, the second stage underflow is controlled so that the solvent diluted tailings 68 are at a temperature T_{UF2} sufficient to facilitate downstream TSRU operation. The T_{UF2} may be at least about 60°C and more preferably range between about 70°C and about 100°C depending on upstream and downstream temperatures and other unit operating conditions, notably pressure.

In another aspect, the difference between T_{UF1} and T_{FSh} may be controlled between about 2°C and about 15°C.

In other optional aspects, the temperatures may be maintained sufficiently high to delay the onset of asphaltene precipitation and allow lower S/B. Diluted froth
5 temperatures about 120°C up to about 130°C may be achieved with direct steam injection to enable advantageous vessel sizing, mixing and separation performance.

In another aspect, the present invention allows reduction of heating of make-up solvent. The first stage underflow contains an amount of solvent and little bitumen such that it is much easier to mix with make-up solvent compared to the bitumen
10 froth. The viscosity of the first stage underflow is much lower than the bitumen froth and the temperature required to achieve effective mixing with the make-up solvent is thus not as high. The second solvent containing stream and the second stage separation vessel may thus be at lower temperatures. A constraint on the second stage separation vessel is to have sufficiently high temperature so as to produce a
15 solvent diluted tailings hot enough to flash in the downstream TSRU. The trim heater for heating the second stage overflow may be configured to tailor the first solvent containing temperature T_{OFSh} to froth quality and maintain constant temperature of the separation, not to heat the froth necessarily.

In another optional aspect, the process includes a step of chemically modifying the
20 viscosity of the bitumen froth. A viscosity modifier may be added to the bitumen froth before or after or in between two heating steps. For instance, referring to Fig 3, a viscosity modifier may be injected into the bitumen froth 12 downstream of the heater 16 and upstream of the additional mixer 82, in this illustrated case as a recirculated diluted bitumen stream 50 from the first stage separation vessel 36. It
25 should be noted, however, that the recirculated diluted bitumen stream 50 may be added upstream or downstream of any one of mixers 82, 30a or 30b or solvent streams 32a or 32b. Preferably, the recirculated diluted bitumen stream 50 is injected into the heated bitumen froth 20 downstream of the heater 16, since the viscosity modifier still needs to be mixable into the bitumen froth stream to modify its
30 viscosity. Thus, addition into the unheated bitumen froth 12 would be less advantageous since the viscosity modifier would not be able to mix as effectively into the froth stream 12. There may also be multiple addition points of the viscosity modifier prior to introduction of the diluted bitumen froth 34 into the separation

vessel 36. The viscosity modifier may be derived from the froth treatment process itself, being a recirculated stream such as recirculated diluted bitumen stream 50; obtained from another oil sands operations such as upgrading or in situ recovery; or provided as a new chemical addition stream, depending on the type of viscosity
5 modifier and available process streams. The viscosity modifier may comprise one or more families of chemicals including naphathenic diluent, paraffinic diluent, light hydrocarbons, other chemical additives, and the like. The viscosity modifier may also be selected to further reduce the viscosity of the froth in response to an increase in temperature. For the case of a paraffinic froth treatment process, the
10 viscosity modifier may be a pre-blending amount of paraffinic solvent which may be a recirculated stream containing paraffinic solvent such as the recirculated diluted bitumen stream 50. Such a pre-blending paraffinic viscosity modifier is preferably added to the froth in an amount below the precipitation concentration to avoid precipitating asphaltenes and thus emphasise the viscosity modification
15 functionality.

In another optional aspect, the solvent containing streams are added and blended in two stages at different S/B. The bitumen froth and first stage underflow streams are thus conditioned according to the characteristics of each stream to add the solvent in the desired amount.

20 As mentioned herein-above, the bitumen froth is heated to a temperature bellow the flash temperature of the solvent to be added. Thus, this temperature will depend on the pressure of the system as well as the type of solvent being used and its vapour pressure at the given temperature. A light solvent such as butane flashes at lower temperatures compared to heavier solvents such as hexane and heptane. For new
25 designs and operationally retrofitting existing systems, in order to increase the upper temperature limit a solvent with a higher flash temperature could be used or the pressure of the system maybe increased. Increasing the pressure of the system, including the separation vessel, may be relatively expensive especially since vapour pressure increases are exponential with respect to rises in temperature. By way of
30 example, for a design pressure of about 1000 kPaa the upper temperature limit constrained by the vapour pressure of pentane as solvent would be about 112 °C and for a design pressure of about 750 kPaa the upper temperature limit constrained by the vapour pressure of pentane as solvent would be about 99°C. In a preferred

aspect, the upper temperature limit is lower than the flashing temperature of the solvent by at least 5°C, preferably by at least about 10°C. In another aspect, the hydraulic liquid load in the separation vessel is also taken into consideration and thus the pressure is provided accordingly lower. In a design with a pressure of about 5 750 kPaa, the temperature may be preferably up to about 100°C and higher temperatures up to 120°C for example could be used with appropriate pressure containment conditions.

EXAMPLES, ESTIMATES & CALCULATIONS

I. Temperature comparison calculation examples

- 10 Calculation and estimate testing were performed to assess the relative effect of increased froth temperature on blending froth with solvent where initial blending of bitumen froth and solvent first breaks the bitumen froth to drops which aids solvent dissolving into bitumen. This included estimation of the relative effect of increased froth temperature on mixing. In the initial mixing and blending of bitumen froth and 15 solvent, it was considered that the bitumen (assume controlling) needs to break down to drops to permit the solvent to dissolve the matrix.

Drop size equations incorporating terms for the viscous resistance to drop breakup are identified in Equation 7-27 of "*Handbook of Industrial Mixing: Science and Practice*", E. Paul et al., John Wiley & Sons, 2004:

20
$$d_{\max} = K_1 \left(\frac{\sigma}{\rho_c} \right)^{0.6} \left(\frac{\rho_c}{\rho_d} \right)^{0.2} \varepsilon^{-0.4} (1 + Vi)$$

Where:

d_{\max} = maximum droplet size

K_1 = constant for specific mixer (in the order of 1.0 : refer to equation 7-24)

σ = surface tension

25 ρ_c = density of the continuous phase (assume in this case hydrocarbon due to volume)

ρ_d = density of viscous dispersed phase: bitumen in froth assumed as controlling

ε = energy intensity = $(\Delta PV)/(\rho L)$

ΔP = pressure drop

V = velocity

L = Length

5 Vi = viscosity number = $u_d V / \sigma (\rho_c / \rho_d)^{0.5}$

u_d = Dispersed phase viscosity/ or elongational viscosity = Newton shear viscosity * 3

Stream	Froth	2 ND Stage O/F	1st stage Feed	1stage O/F
Temperature C	82.5	80	80.1	80
Density kg/m ³	1032	589	759	673
Viscosity cP	1815.82	0.16	1.55	0.74
Bitumen wt%	52.48	3.26	28.92	35.50
Solvent wt%	0.00	96.64	46.25	64.36

In case 1, two situations were considered: bitumen froth at 70°C and at 90°C, each blended in a 24 NPS mixer pipe with 2nd stage O/F to froth settler vessel at 80°C.

D= Pipe ID m	0.575	
V= Velocity m/s	3.42	based on bulk flow volume
Empty pipe shear rate G' (S ⁻¹)	47.5	where $G' = 8V/D$ Eq 7-21
Reynolds Number	1785	Laminar continuous hydrocarbon phase
friction factor f	0.0090	Laminar = $16/Nre$
ΔP = pressure drop/meter	30.8	empty pipe kPa/m = $4 * f * \Delta V^2 / (D * 2) / 1000$

10

Bitumen Phase	Situation 1	Situation 2	
Temperature °C	70	90	
Density kg/m ³	987.4	975.4	Bitumen density at temperature
Viscosity (cP)	626	176	Bitumen viscosity at temperature
u_d	1878	529	Dispersed phase viscosity
σ (mN/m)	13	11	s = surface tension: AOSTRA 1989 Figure 5: 1 g/L NaCl

Calculation of viscosity number

	Situation 1	Situation 2	
ρ_c (kg/m ³)	673	673	ρ_c = density of the continuous phase
V (m/s)	3.42	3.42	velocity based on bulk flow
Vi	407	136	Vi = viscosity number

Calculation of energy intensity: based on empty pipe

	Situation 1	Situation 2	
$\Delta P / L$	30.8	30.8	Empty pipe/ bulk stream properties

ϵ	0.139	0.139	Same end mixture.
K_1	1.0	1.0	Constant in the order of 1.0

Calculation of d_{max} per equation defined above

	Situation 1	Situation 2
d_{max}	78.1	23.8
Surface area / drop	19153	1783
Volume/ drop	249253	7082
Drops per unit volume	1	35
Net surface area	19153	62767

- In conclusion, the reduced viscosity by increasing froth temperature 20°C improves
 5 blending of bitumen froth and solvent by smaller droplets or increased surface area.

Δd_{max}	30.5%
Δ Surface Area	3.28

II. Example froth properties

Density and viscosity of raw bitumen related to temperature is presented in Figs 4 and 5.

10 *Density*

- Density (SG) for hydrocarbons reduces as temperature increases approximately linearly except when approaching critical temperature. For an exemplary range of interest, consider up to 130°C, bitumen is well below critical temperature. Density of raw bitumen correlates as follows: Density (g/cm³) @ temp = -0.0006* (Temp in K
 15 or C +273) + 1.1932. See Fig 4.

Viscosity

- Viscosity of raw bitumen generally follows Andrade equation (from Perry's Handbook, 6th Edition). $\ln(h_L) = A + B/T$, where h_L is the liquid viscosity in centipoises (cP), cP = mPa.s, T is the temperature in K, C + 273; $\ln(h_L) = A + B/T$
 20 = 16.56-7888.8/T (K).

Bitumen viscosity dependency on temperature:

$$h_L = e^{(-16.56+7888.8/T)}$$

See Fig 5.

III. Comparative conceptual examples

In order to illustrate certain aspects and embodiments of the present invention, comparative conceptual examples are presented herein-below. The terms used for the various stream temperatures are illustrated in Fig 2.

Comparative Example A

5 A1: High temperature bitumen froth heating

$$T_{Fi} = 65^{\circ}\text{C}$$

$$T_{Fh} = 90^{\circ}\text{C}$$

$$\text{Froth bitumen } d_{\max} = 23.8 \mu\text{m}$$

$$\text{Froth bitumen viscosity} = 176 \text{ cP}$$

10 Froth bitumen density = 975.5 kg/m^3

$$T_{\text{OFSi}} = 75^{\circ}\text{C}$$

$$T_{\text{OFSH}} = 80^{\circ}\text{C}$$

$$T_{\text{DF}} = 87.5^{\circ}\text{C}$$

$$T_{\text{SEP1}} = 87.5^{\circ}\text{C}$$

15 $T_{\text{UF1}} = 85^{\circ}\text{C}$

$$T_{\text{FSi}} = 60^{\circ}\text{C}$$

$$T_{\text{FSh}} = 75^{\circ}\text{C}$$

$$T_{\text{DUF}} = 80^{\circ}\text{C}$$

$$T_{\text{SEP2}} = 80^{\circ}\text{C}$$

20 A2: Solvent heating for temperature control

$$T_{Fi} = T_{Fh} = 65^{\circ}\text{C}$$

$$\text{Froth bitumen } d_{\max} > 78.1 \mu\text{m}$$

$$\text{Froth bitumen viscosity} > 626 \text{ cP}$$

$$\text{Froth bitumen density} > 987.4 \text{ kg/m}^3$$

25 $T_{\text{OFSi}} = 75^{\circ}\text{C}$

$$T_{\text{OFSH}} = 110^{\circ}\text{C}$$

$$T_{DF} = 87.5^{\circ}\text{C}$$

$$T_{SEP1} = 87.5^{\circ}\text{C}$$

$$T_{UF1} = 85^{\circ}\text{C}$$

$$T_{FSi} = 60^{\circ}\text{C}$$

$$5 \quad T_{FSh} = 75^{\circ}\text{C}$$

$$T_{DUF} = 80^{\circ}\text{C}$$

$$T_{SEP2} = 80^{\circ}\text{C}$$

Comparing examples A1 and A2, both first and second stage separation vessels as well as several process streams are operated at identical temperatures. However, example A1 imparts heating energy to the bitumen froth stream resulting in low viscosity and superior froth-solvent mixing characteristics compared to example A2.

Comparative Example B

B1: High temperature bitumen froth heating with low solvent heating

$$T_{Fi} = 65^{\circ}\text{C}$$

$$15 \quad T_{Fh} = 95^{\circ}\text{C}$$

$$\text{Froth bitumen } d_{\max} < 23.8 \mu\text{m}$$

$$\text{Froth bitumen viscosity} < 176 \text{ cP}$$

$$\text{Froth bitumen density} < 975.5 \text{ kg/m}^3$$

$$T_{OFSi} = 75^{\circ}\text{C}$$

$$20 \quad T_{OFSh} = \text{approximately } 75^{\circ}\text{C with optional trim heating } 1\text{-}2^{\circ}\text{C}$$

$$T_{DF} = 85^{\circ}\text{C}$$

$$T_{SEP1} = 85^{\circ}\text{C}$$

$$T_{UF1} = 82.5^{\circ}\text{C}$$

$$T_{FSi} = 60^{\circ}\text{C}$$

$$25 \quad T_{FSh} = \text{approximately } 60^{\circ}\text{C with optional trim heating } 1\text{-}2^{\circ}\text{C}$$

$$T_{DUF} = 75^{\circ}\text{C}$$

$$T_{SEP2} = 75^{\circ}\text{C}$$

B2: Solvent heating for temperature control

$$T_{Fi} = 65^{\circ}\text{C}$$

$$T_{Fh} = 70^{\circ}\text{C}$$

$$\text{Froth bitumen } d_{\max} = 78.1 \text{ } \mu\text{m}$$

$$5 \quad \text{Froth bitumen viscosity} = 626 \text{ cP}$$

$$\text{Froth bitumen density} = 987.4 \text{ kg/m}^3$$

$$T_{\text{OFSi}} = 75^{\circ}\text{C}$$

$$T_{\text{OFSh}} = 100^{\circ}\text{C}$$

$$T_{\text{DF}} = 85^{\circ}\text{C}$$

$$10 \quad T_{\text{SEP1}} = 85^{\circ}\text{C}$$

$$T_{\text{UF1}} = 82.5^{\circ}\text{C}$$

$$T_{\text{FSi}} = T_{\text{FSh}} = 60^{\circ}\text{C}$$

$$T_{\text{DUF}} = 75^{\circ}\text{C}$$

$$T_{\text{SEP2}} = 75^{\circ}\text{C}$$

15 B3: Fresh solvent heating for temperature control

$$T_{Fi} = T_{Fh} = 65^{\circ}\text{C}$$

$$\text{Froth bitumen } d_{\max} < 78.1 \text{ } \mu\text{m}$$

$$\text{Froth bitumen viscosity} < 626 \text{ cP}$$

$$\text{Froth bitumen density} < 987.4 \text{ kg/m}^3$$

$$20 \quad T_{\text{OFSi}} = 80^{\circ}\text{C}$$

$$T_{\text{DF}} = 70^{\circ}\text{C}$$

$$T_{\text{SEP1}} = 70^{\circ}\text{C}$$

$$T_{\text{UF1}} = 67.5^{\circ}\text{C}$$

$$T_{\text{FSi}} = 60^{\circ}\text{C}$$

$$25 \quad T_{\text{FSh}} = 90^{\circ}\text{C}$$

$$T_{\text{DUF}} = 80^{\circ}\text{C}$$

$$T_{SEP2} = 80^{\circ}\text{C}$$

Comparing examples B1 and B2, both first and second stage separation vessels as well as several process streams are operated at identical temperatures. However, example B1 imparts heating energy to the bitumen froth stream resulting in low viscosity and superior froth-solvent mixing characteristics compared to example B2.

Comparing examples B1 and B3, the temperature control strategy is quite different particularly insofar as in B1 the first stage separation vessel is hotter than the second and in B3 the second stage separation vessel is hotter than the first. Example B1 has the marked advantage of lowering the viscosity of the bitumen froth stream for superior froth-solvent mixing characteristics compared to example B3.

Indeed, the same amount of heat energy can be imparted in different ways to different streams to achieve the same operational temperature in the separation vessels, e.g. comparative examples A1 versus A2 and B1 versus B2. In embodiments of the present invention, the heat energy is used advantageously to emphasize bitumen froth heating to achieve improved solvent-froth mixing and separation performance particularly in the first stage separation vessel.

It is worth mentioning that throughout the preceding description when the article "a" is used to introduce an element it does not have the meaning of "only one" it rather means of "one or more". For instance, the apparatus according to the invention can be provided with two or more separation vessels, etc. without departing from the scope of the present invention.

While the invention is described in conjunction with example embodiments, it will be understood that it is not intended to limit the scope of the invention to such embodiments. On the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included as defined by the present description. The objects, advantages and other features of the present invention will become more apparent and be better understood upon reading of the following detailed description of the invention, given with reference to the accompanying drawings.

CLAIMS

1. A method for pre-treating bitumen containing froth for mixing with a paraffinic solvent containing stream to produce a diluted froth for introduction into a separation apparatus for separation into a diluted bitumen component and a solvent diluted tailings component, the method comprising heating the bitumen froth to produce a heated froth with a reduced viscosity and a froth-solvent mixing temperature that is below a flash temperature of the solvent and ranging from about 75°C to about 95°C, the heated bitumen froth viscosity being at most about 700 cP higher than a solvent stream viscosity.
2. The method of claim 1, wherein the bitumen froth has a bitumen content between about 40 wt% and about 75 wt%.
3. The method of claim 2, comprising adapting the heating of the bitumen froth in accordance with the bitumen content thereof.
4. The method of any one of claims 1 to 3, wherein the heating is conducted by direct steam injection.
5. The method of any one of claims 1 to 4, wherein the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} of at most about 100 μm .
6. The method of any one of claims 1 to 4, wherein the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} in between about 100 μm and about 25 μm .
7. The method of any one of claims 1 to 6, wherein the heating is conducted to control the reduced bitumen viscosity of at most about 650 cP.
8. The method of any one of claims 1 to 6, wherein the heating is conducted to control the reduced bitumen viscosity in between about 100 cP and about 650 cP.
9. The method of any one of claims 1 to 8, wherein the heating is conducted to provide the reduced bitumen viscosity between about 1.5 times and about 100 times lower than the viscosity of the bitumen in the froth.

10. The method of any one of claims 1 to 9, wherein the heating is conducted to control the froth-solvent mixing temperature at least about 10°C below the flash temperature of the solvent.
11. The method of any one of claims 1 to 10, wherein the heating is conducted to
5 reduce a bitumen/solvent viscosity ratio by at least about an order of magnitude.
12. The method of any one of claims 1 to 11, wherein the heating is conducted to control the froth-solvent mixing temperature above a temperature of the solvent.
13. The method of claim 12, wherein the froth-solvent mixing temperature is at least about 10°C above the temperature of the solvent.
- 10 14. The method of claim 1, wherein the separation apparatus comprises a first stage separation vessel and a second stage separation vessel in counter-current configuration.
15. The method of claim 14, comprising:
- 15 supplying the diluted froth to the first stage separation vessel and producing the diluted bitumen component and a first stage underflow component;
- adding a make-up solvent stream to the first stage underflow component to produce a diluted first stage underflow;
- supplying the diluted first stage underflow to the second stage separation vessel and producing a second stage overflow component and a second
20 stage underflow component as the solvent diluted tailings component; and
- supplying the second stage overflow component as the solvent containing stream added to the heated froth.
16. The method of claim 15, comprising trim heating the solvent containing stream to control temperatures of the diluted froth and the first stage separation vessel.
- 25 17. The method of claim 15 or 16, comprising trim heating the make-up solvent stream to control temperatures of the diluted first stage underflow to the second stage separation vessel.
18. The method of any one of claims 15 to 17, comprising maintaining a first operating temperature of the first stage separation vessel above a second
30 operating temperature of the second stage separation vessel.

19. The method of any one of claims 15 to 18, comprising providing the make-up solvent stream cooler than the solvent containing stream added to the heated froth.
- 5 20. The method of any one of claims 14 to 19, comprising subjecting the solvent diluted tailings component to solvent recovery flashing and operating the second stage separation vessel such that the solvent diluted tailings component has a temperature suitable for the solvent recovery flashing.
- 10 21. A method of improving energy use in a froth treatment operation, the froth treatment operation comprising adding a paraffinic solvent containing stream to bitumen froth to produce a diluted froth, introducing the diluted froth into a separation apparatus and producing from the separation apparatus a diluted bitumen component and a solvent diluted tailings component, the method comprising:
- 15 reducing heat provided to the solvent containing stream thereby producing a temperature-reduced solvent stream;
- increasing heat provided to the bitumen froth prior to adding the solvent containing stream thereto to produce a heated froth with a froth-solvent mixing temperature that is below a flash temperature of the solvent and suitably high to provide a reduced bitumen viscosity; and
- 20 adding the temperature-reduced solvent to the heated froth and thereby producing the diluted froth for separation.
22. The method of claim 21, wherein the bitumen froth has a bitumen content between about 40 wt% and about 75 wt%.
- 25 23. The method of claim 22, comprising adapting the heating of the bitumen froth in accordance with the bitumen content thereof.
24. The method of any one of claims 21 to 23, wherein the heating is conducted by direct steam injection.
25. The method of any one of claims 21 to 24, wherein the heating is conducted to control the froth-solvent mixing temperature above about 60°C.
- 30 26. The method of any one of claims 21 to 24, wherein the heating is conducted to control the froth-solvent mixing temperature above about 70°C.

27. The method of any one of claims 22 to 26, wherein the heating is conducted to control the froth-solvent mixing temperature above about 90°C.
28. The method of any one of claims 21 to 24, wherein the heating is conducted to control the froth-solvent mixing temperature in between about 90°C and about 120°C.
29. The method of any one of claims 21 to 28, wherein the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} of at most about 100 μm .
30. The method of any one of claims 21 to 28, wherein the heating is conducted to cause formation of bitumen droplets having a maximum droplet size d_{\max} in between about 100 μm and about 25 μm .
31. The method of any one of claims 21 to 30, wherein the heating is conducted to control the reduced bitumen viscosity of at most about 650 cP.
32. The method of any one of claims 21 to 30, wherein the heating is conducted to control the reduced bitumen viscosity in between about 100 cP and about 650 cP.
33. The method of any one of claims 21 to 32, wherein the heating is conducted to provide the reduced bitumen viscosity between about 1.5 times and about 100 times lower than the viscosity of the bitumen in the froth.
34. The method of any one of claims 21 to 33, wherein the heating is conducted to control the froth-solvent mixing temperature at least about 10°C below the flash temperature of the solvent.
35. The method of any one of claims 21 to 34, wherein the heating is conducted to reduce a bitumen/solvent viscosity ratio by at least about an order of magnitude.
36. The method of any one of claims 21 to 35, wherein the heating is conducted to control the froth-solvent mixing temperature above a temperature of the solvent.
37. The method of claim 36, wherein the froth-solvent mixing temperature is at least about 10°C above the temperature of the solvent.

38. The method of claim 21, wherein the separation apparatus comprises a first stage separation vessel and a second stage separation vessel in counter-current configuration.
39. The method of claim 38, comprising:
- 5 supplying the diluted froth to the first stage separation vessel and producing the diluted bitumen component and a first stage underflow component;
- adding a make-up solvent stream to the first stage underflow component to produce a diluted first stage underflow;
- 10 supplying the diluted first stage underflow to the second stage separation vessel and producing a second stage overflow component and a second stage underflow component as the solvent diluted tailings component; and
- supplying the second stage overflow component as the solvent containing stream added to the heated froth.
40. The method of claim 39, comprising trim heating the solvent containing stream
- 15 to control temperatures of the diluted froth and the first stage separation vessel.
41. The method of claim 39 or 40, comprising trim heating the make-up solvent stream to control temperatures of the diluted first stage underflow to the second stage separation vessel.
42. The method of any one of claims 39 to 41, comprising maintaining a first
- 20 operating temperature of the first stage separation vessel above a second operating temperature of the second stage separation vessel.
43. The method of any one of claims 39 to 42, comprising providing the make-up solvent stream cooler than the solvent containing stream added to the heated froth.
- 25 44. The method of any one of claims 21 to 43, comprising subjecting the solvent diluted tailings component to solvent recovery flashing and operating the second stage separation vessel such that the solvent diluted tailings component has a temperature suitable for the solvent recovery flashing.

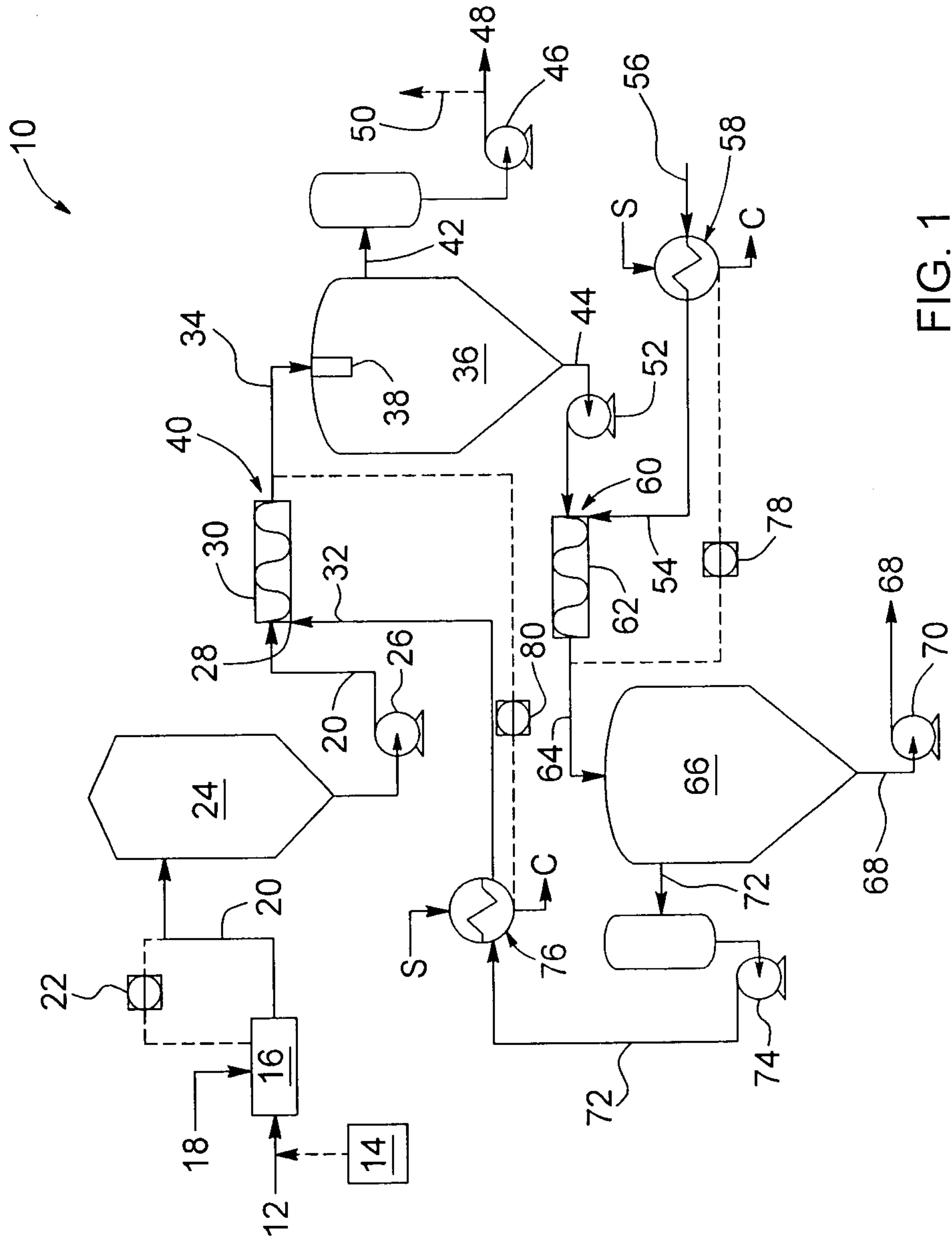


FIG. 1

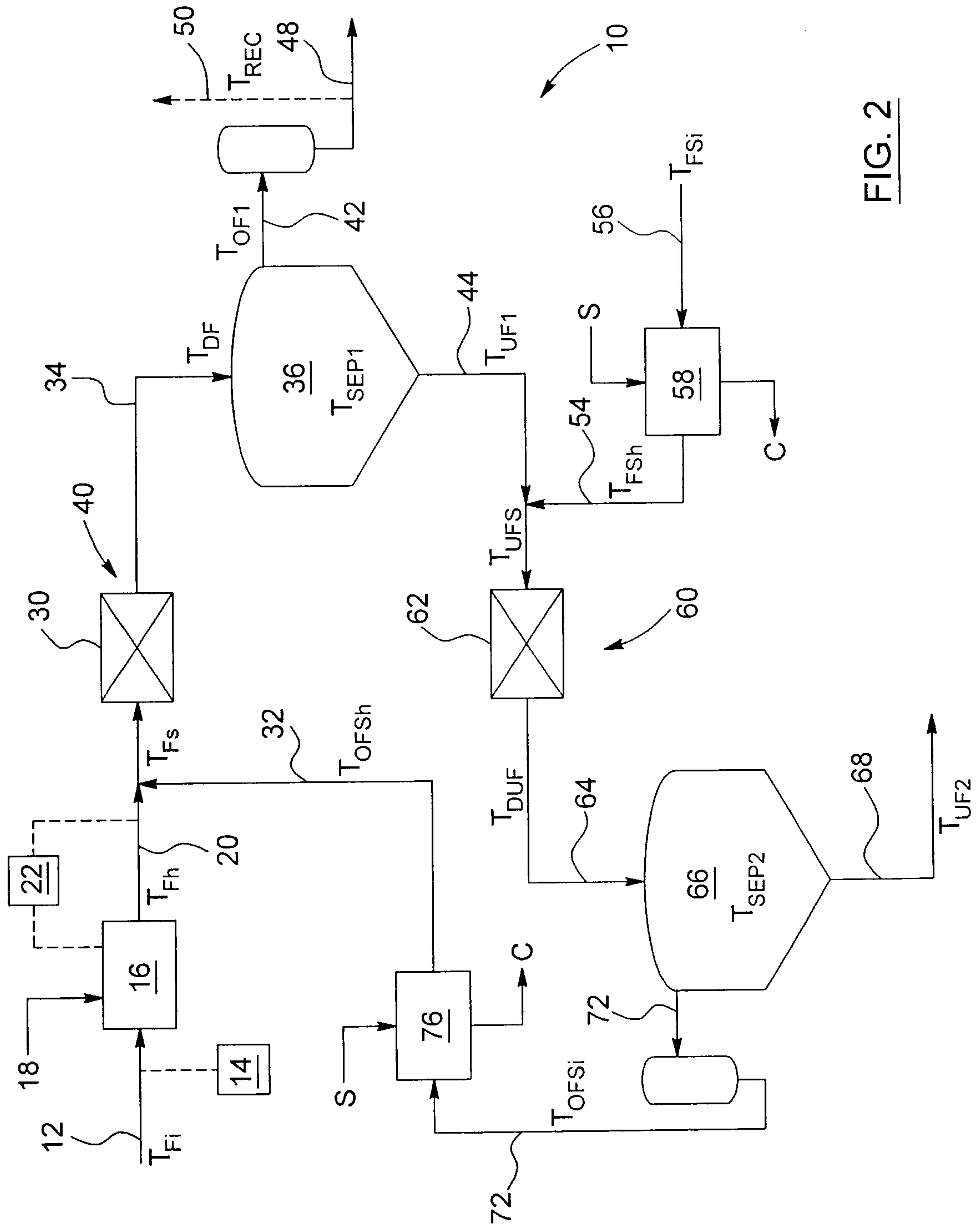


FIG. 2

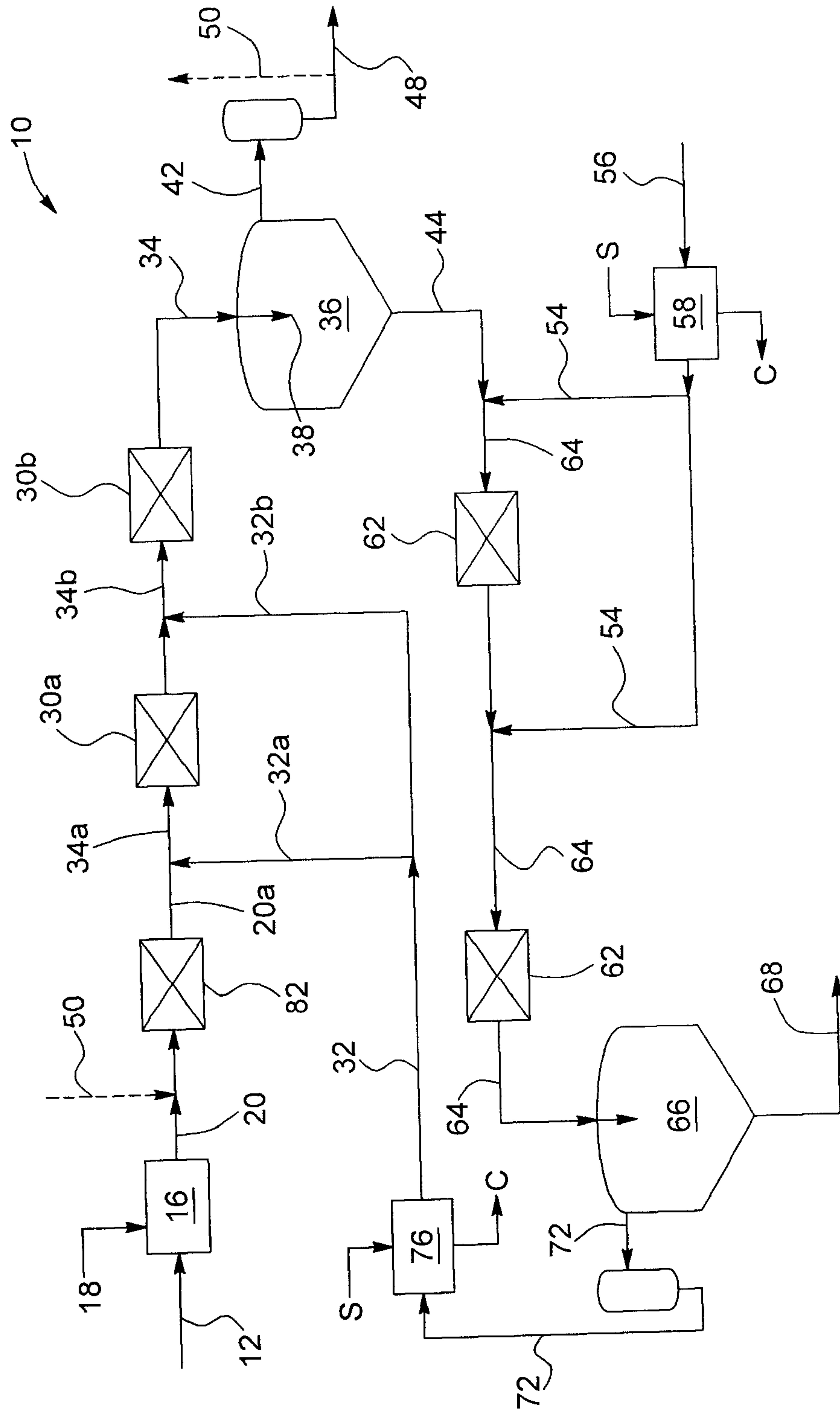


FIG. 3

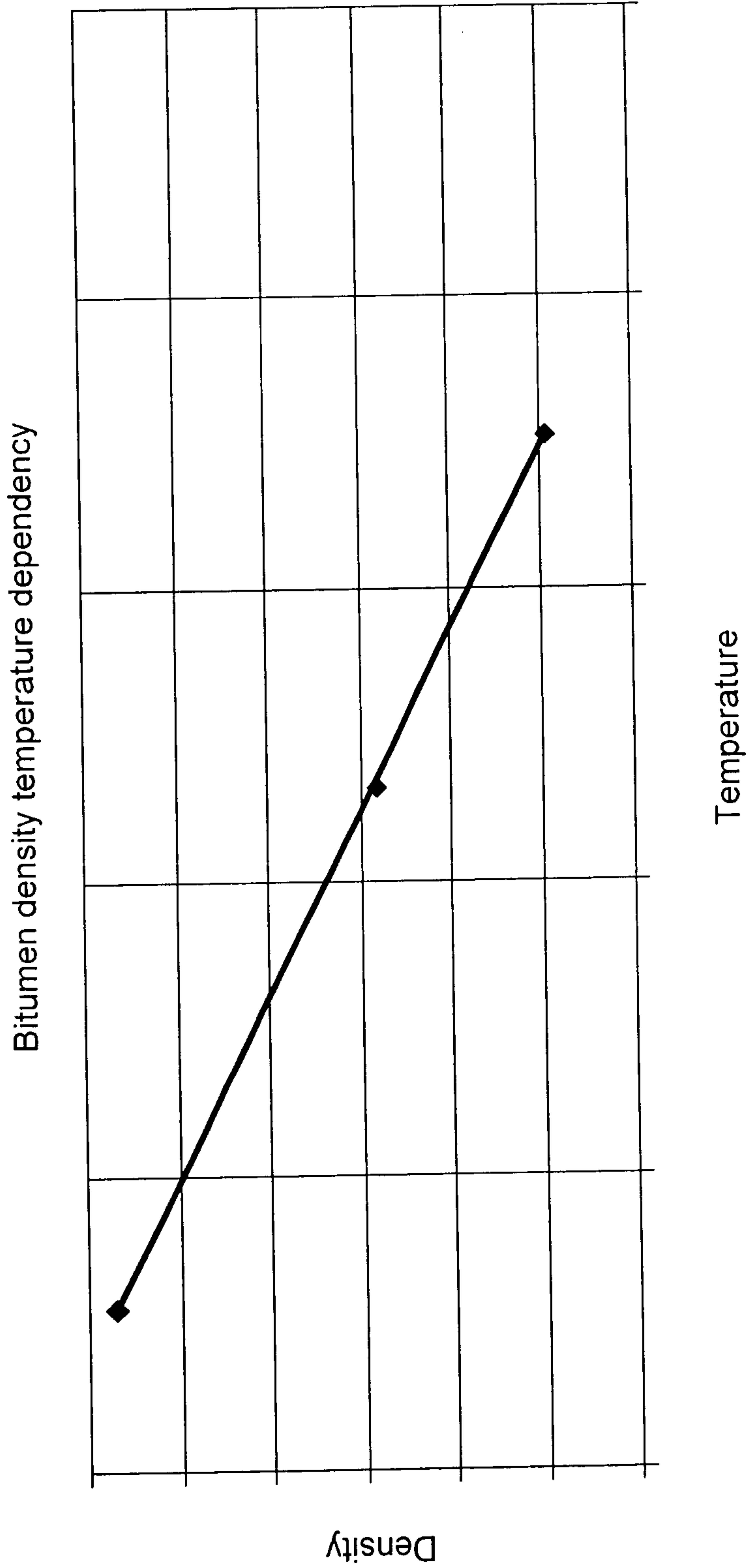


FIG. 4

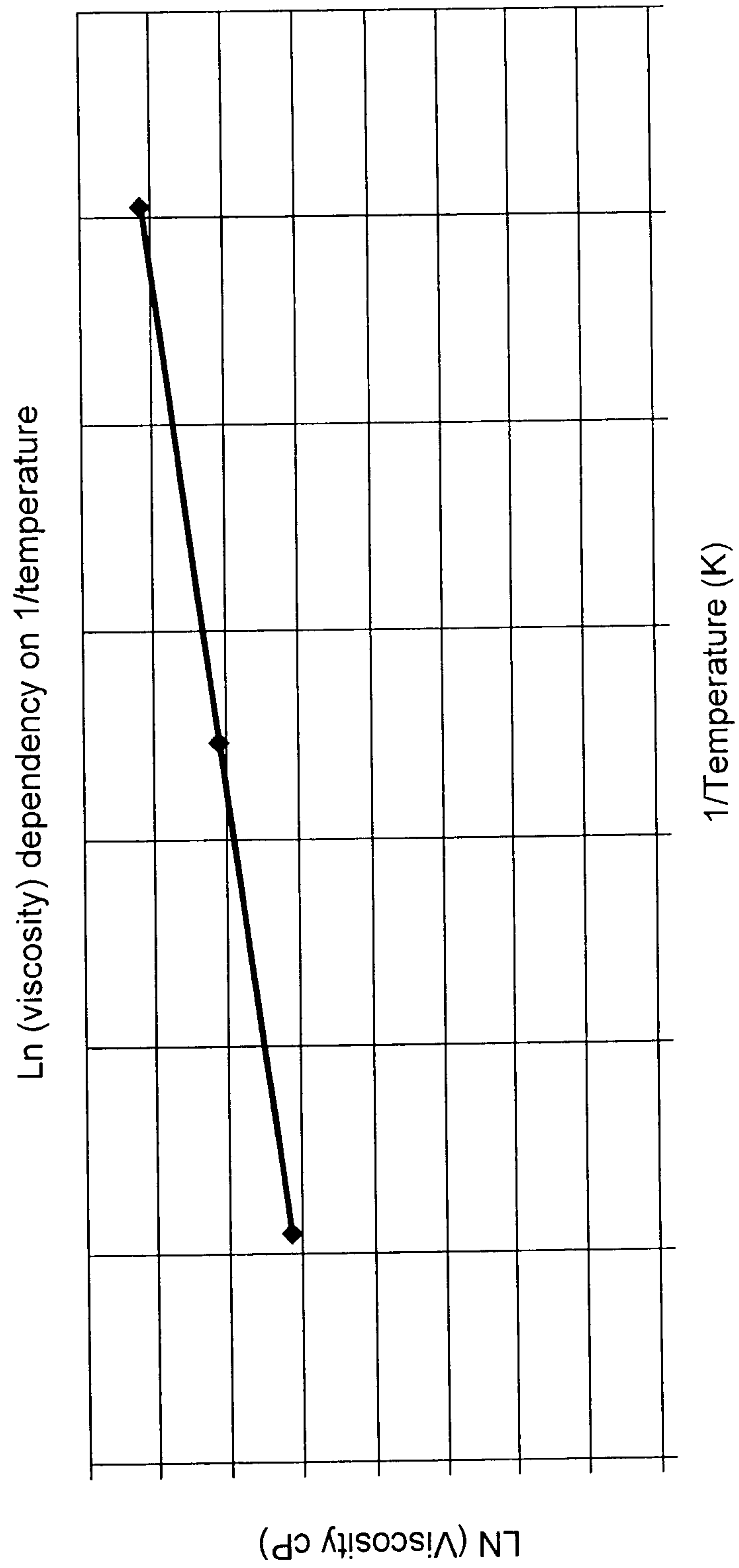


FIG. 5

