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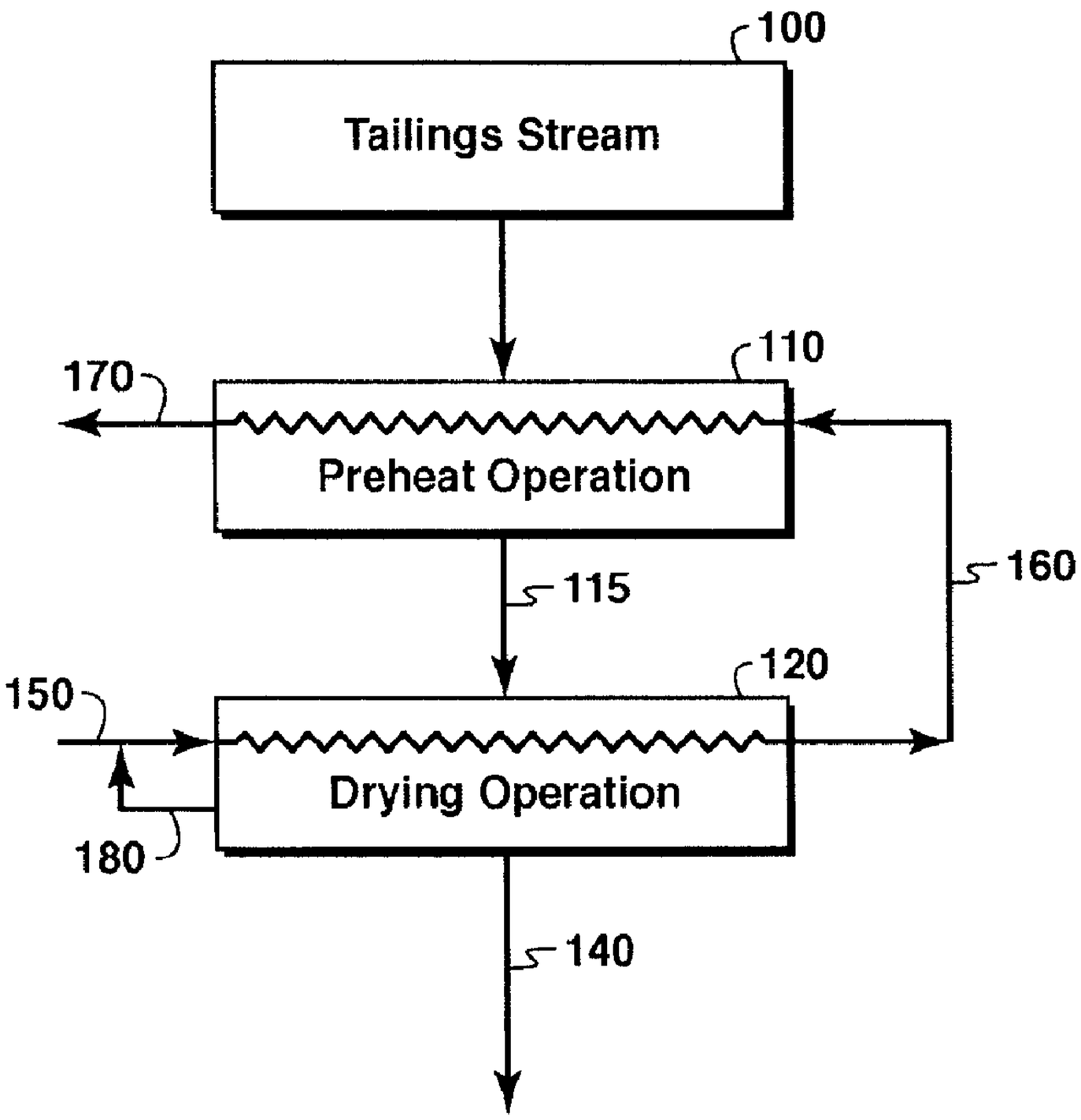
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(54) Title: HEAT AND WATER RECOVERY FROM OIL SANDS WASTE STREAMS



(57) Abrégé/Abstract:
Methods and systems for recovering heat and water from waste streams produced during oil sands extraction to form dry, stackable tailings. A tailings stream is preheated in a heat exchanger, thereby reducing the energy required to dry the tailings. The

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ABSTRACT

Methods and systems for recovering heat and water from waste streams produced during oil sands extraction to form dry, stackable tailings. A tailings stream is preheated in a heat exchanger, thereby reducing the energy required to dry the tailings. The preheated tailings are then dried, thereby reducing the tailings to dry stackable tailings or thickened tailings suitable for mine backfill. Heat and high-quality water are recovered from the drying operation and re-used in the preheat operation, or in other steps of oil sands extraction or treatment processes, thereby reducing the overall heat and water requirements.

HEAT AND WATER RECOVERY FROM OIL SANDS WASTE STREAMS

FIELD OF THE INVENTION

[0001] The present invention relates generally to recovery of heat and water from waste streams produced during oil sands extraction.

BACKGROUND OF THE INVENTION

[0002] Oil sands are deposits comprised of bitumen, clay, sand, and connate water, and make up a significant portion of North America's naturally-occurring petroleum reserves. To produce a marketable hydrocarbon product from the oil sands, the bitumen must be recovered from the oil sands matrix. Depending on geographic location, bitumen may be recovered by surface mining or in-situ thermal methods, such as steam assisted gravity drainage (SAGD), cyclic steam stimulation (CSS), vapor extraction process (VAPEX), liquid addition to steam for enhancing recovery (LASER) or derivatives thereof.

[0003] Because the bitumen itself is a highly viscous material, separating it from the extracted sands poses certain practical difficulties. The common industry practice for bitumen recovery (or extraction) from surface mineable oil sands is based on the Clark Hot Water Extraction (CHWE) process. This process is a water-based bitumen extraction process, where hot water, air, and process aides are added to crushed ore. An oil-rich froth “floats” or rises through the mixture as a hydrocarbon phase. The result is an extract that typically comprises two parts: a hydrocarbon phase known as a bitumen froth stream, made up of bitumen, water and fine solids, and an aqueous phase known as extraction tailings, made up of coarse solids, fine solids, water and some unrecovered hydrocarbon. The bitumen froth stream typically comprises bitumen (approximately 60% by weight), water (approximately 30% by weight) and solids (approximately 10% by weight), and must undergo a froth treatment process to separate the organic compounds from the water and the solid contaminants. Due to the high viscosity of the bitumen froth, the first step is typically the introduction of a solvent, usually a hydrocarbon solvent such as a naphtha or a paraffinic solvent. This step is known as froth separation (FS), and helps to accelerate the separation of solid particles dispersed within the froth by both increasing the density differential between the bitumen, water, and solids and lowering bitumen viscosity. Separation is carried out by any number of methods, such as centrifugation or simply allowing solids to settle by gravity. The result of the froth treatment process is diluted bitumen and a second tailings stream,

The result of the froth treatment process is diluted bitumen and a second tailings stream, known as froth treatment tailings, made up of water, solids, residual solvent and residual hydrocarbon, that requires secondary treatment to recover the residual solvent and prepare the tailings for disposal. The first step in this secondary treatment process is to recover as much of the residual organic solvent as possible through any number of processes known collectively as tailings solvent recovery (TSR). Recovered solvent can then be reused in the FS process. Tailings from a TSR unit, known as TSRU tailings, are then disposed of into storage (or tailings) ponds. The specific properties of the tailings will vary depending on the extraction method and processing step from which they originate, but in all cases, the tailings streams are essentially spent water, process aids, residual hydrocarbon and waste solids left over once the usable bitumen has been removed.

[0004] While effective, the extraction treatment processes require the use of significant quantities of water, and heat to raise the temperature of the water, which significantly increases the cost associated with recovery of petroleum from the bitumen-laden oil sands. Most of the process inputs, including the water and energy used in the processes end up in the product streams; over 60% of the enthalpy invested in the extraction process is "lost" to the tailings stream, along with approximately three barrels of water per barrel of bitumen extracted.

[0005] One known method of recovering the water is to simply store the tailings stream in tailings ponds, and allow the solid components to settle and separate from the water over time. The heat content of tailings escapes into the atmosphere, while the tailings water is retained for future use, with some loss due to evaporation. This tailings storage method is ineffective for at least three reasons: firstly, it is not very efficient, as a significant amount of time is required for most of the solid materials to settle out of the tailings by operation of gravity alone; secondly, it does not allow for the recovery of any of the large amount of energy contained within the tailings stream in the form of heat, which is significant, as tailings are initially sent to the ponds for storage at temperatures between 20 and 90 °C; thirdly, the resulting tailings ponds are voluminous, occupying a large footprint of land that cannot be used for any other purposes during the settling process.

[0006] Rather than simply storing the tailings in ponds, it is desirable to recover as much of the invested water and enthalpy from the tailings stream as possible to reduce the overall cost of extracting bitumen from the oil sands, to minimize land footprint and to minimize fresh water withdrawal. The energy and water recovered can ideally be reused in

the extraction process. This has the advantage of improving the overall energy efficiency of the extraction process. It is further desirable to minimize the volume of tailings that must be disposed. By removing as much water as possible from tailings, the waste streams can be substantially reduced to the sand, clay and other minerals originally extracted from the oil sands. In this form, the tailings can be easily disposed of through, for example, direct mine refill to reduce or eliminate tailings ponds and minimize land footprint.

[0007] Several attempts to recover heat, water and other reagents from tailings streams are known. Exemplary methods are disclosed in U.S. Patent Nos. 4,343,691, 4,561,965 and 4,240,897, all to Minkkinen. These patents are directed to heat and water vapor recovery using a humidification/dehumidification cycle. U.S. Patent No. 6,358,403 to Brown et al. described a vacuum flash process used to recover hydrocarbon solvents from heated tailings streams. There has been, however, a lack of success in effective water and energy recovery.

[0008] For both economic and environmental reasons, it is desirable to provide an alternative method for recovering water and energy from tailings streams, as well as to reduce the overall volume of tailings that must be disposed of.

SUMMARY OF THE INVENTION

[0009] It is therefore an object of the present invention to obviate or mitigate at least one disadvantage of known systems or methods.

[0010] In one aspect, there is provided methods and systems for treating tailings produced during oil sands extraction. A tailings stream is preheated in a heat exchanger, thereby reducing the energy required to dry the tailings. The preheated tailings are then dried, thereby changing the tailings to dry stackable tailings or thickened tailings suitable for mine backfill. Heat and high-quality water are recovered from the drying operation and re-used in the preheat operation, or in the oil sands extraction process, thereby reducing the overall heat and water requirements.

[0011] In accordance with another aspect, there is provided a method for treating a tailings stream produced during extraction of bitumen from oil sands, comprising: drying the tailings stream in a dryer using input steam in indirect thermal contact with the tailings stream to produce a dried tailings stream, whereby the input steam and evaporated water from the tailings evaporated during drying convert to a condensed water effluent; and recycling steam

produced from the dryer back into the dryer, wherein the input steam comprises the recycled steam and optionally make-up steam.

[0012] In accordance with yet another aspect, there is provided a system for treating a tailings stream produced during extraction of bitumen from oil sands, comprising: a dryer for receiving the tailings stream and input steam, drying the tailings stream using heat from the input steam, and producing a condensed water effluent; and a steam recycling unit for recycling steam produced from the dryer back into the dryer, wherein the input steam comprises the recycled steam and optionally make-up steam.

[0013] In accordance with still another aspect, there is provided a method for treating a tailings stream produced during extraction of bitumen from oil sands, comprising: a) introducing the tailings stream and a flue gas into a first heat exchanger to preheat the tailings stream, b) introducing the tailings stream into a second heat exchanger to preheat the tailing stream, wherein step a) is performed before step b) or step b) is performed before step a), to produce a preheated tailings stream, c) drying the preheated tailings stream in a dryer using input steam and evaporated water from the preheated tailings evaporated during drying produced vapor in indirect thermal contact with the preheated tailings stream to produce a dried tailings stream, whereby the input steam and the evaporated water from the preheated tailings convert to a condensed water effluent, and d) passing the condensed water effluent from the dryer to the second heat exchanger to preheat the tailings stream.

[0014] In accordance with still another aspect, there is provided a system for treating a tailings stream produced during extraction of bitumen from oil sands, comprising: a first heat exchanger for receiving the tailings stream and a flue gas, and preheating the tailings stream using heat from the flue gas; a second heat exchanger for receiving the tailings stream and a condensed water effluent and preheating the tailings stream using heat from the condensed water effluent, wherein the first or the second heat exchanged is placed upstream of the other; and a dryer for receiving the preheated tailings stream and input steam, heating the preheated tailings stream using heat from the input steam to produce a dried tailings stream, and producing the condensed water effluent produced in the second heat exchanger.

[0015] Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying Figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Embodiments of the present invention will now be described, by way of example only, with reference to the attached Figures, wherein:

Fig. 1 is a flow diagram illustrating an overview of a method of tailings treatment according to one disclosed embodiment;

Fig. 2 is a schematic of an example of a tailings treatment system in accordance with one disclosed embodiment; and

Fig. 3 is a schematic of an example of a tailings treatment system using a flue gas in accordance with one disclosed embodiment.

DETAILED DESCRIPTION

[0017] Generally, in one embodiment the present invention provides a method and system for using drying to recover water and heat energy from tailings streams in oil sands extraction, such as mature fine tailings, coarse tailings, TSRU tailings, fine tailings, and froth separation tailings. Because of the high energy required by conventional drying, using it in the tailings treatment process has not previously been considered practical; however, by recovering heat energy from the evaporated water through drying in accordance with one aspect of the present invention, drying processes may now form an integral part of the treatment process. As will become apparent in view of the following examples and embodiments, water and heat recovered during drying of a tailings stream can be used to preheat the rest of the tailings stream, thereby reducing the amount of energy required to be input for the drying operation. Preheating is optional. While the following examples are presented in the context of tailings streams generated by a bitumen extraction process, one of ordinary skill in the art will appreciate that embodiments of the present invention may be implemented in any oil sands extraction process that produces a stream of tailings comprising solid(s) and liquid(s). The system and methods described herein are equally applicable to any process using or generating any aqueous slurry or mine tailings. For the purposes of this description, the general terms “tailings” and “tailings stream” will be used to denote any aqueous slurry, mine tailings or other solid-liquid mixture used or generated in mining or industrial operations from which heat and/or water can be recovered. Further, the tailings may be provided directly from the extract from the oil sands, from any secondary (or subsequent) recovery or any portion of the process that generates water and/or solids

including tailings ponds. The tailings may or may not also comprise solvents which were added to the oil sands to assist in the bitumen extraction process.

[0018] A drying operation generally comprises heating the tailings stream, thereby providing energy required for the water in the stream to undergo vaporization. Once the phase change occurs, water vapor is liberated from the tailings stream and can be collected through a variety of methods, including, but not limited to, vacuum or steam sweeping. In a drying operation, a dryer must first add sufficient heat, referred to here as sensible heat, to raise the temperature of the tailings stream to the boiling point of water. The dryer must then add the energy required for the water to undergo the change from its liquid phase to its vapour phase. This energy is typically referred to as the heat of vaporization. At all practicable pressures, however, the drying process requires the addition of a substantial amount of energy. In fact, the major part of heating requirement can be captured from the vapour produced during drying. In accordance with one aspect of the present invention, the recovered heat can be sent directly to the drying operation. Any recovered heat can be supplemented by additional energy added to the drying operation through a heat transfer medium such as fuel or steam to reach the energy threshold required for the drying process.

[0019] Figure 1 shows a general overview of an embodiment of the invention. Tailings stream **100** from a bitumen separation process undergoes preheat **110**. The preheat step is optional. A heat exchanger is particularly suitable for the preheat operation, as it allows for indirect transfer of heat from one substance to another by conduction through a wall or other barrier separating the two substances. In this manner, the two substances may exchange heat between one another without ever coming in direct contact with one another or being mixed in any way. Because of the nature of tailings streams in oil sands extraction, the environment within the heat exchanger may be highly susceptible to fouling, or the accumulation of solid material along its inner surfaces. Accordingly, in one embodiment of the invention, the heat exchanger is a self-cleaning heat exchanger of any self cleaning technology known in the art. Examples include circulating fluidized bed exchangers (such as those designed by Klaren BV, Rotterdam, The Netherlands), turbulence inducing or scraping devices, or heat exchangers with an on-line cleaning design (using circulating balls), etc. However, as one of ordinary skill in the art will appreciate, other heat exchangers capable of indirect transfer of heat from either a liquid or gaseous substance to a tailings stream may be used.

[0020] By way of background in respect of circulating fluidized bed exchangers designed by Klaren, BV, self-cleaning heat exchange technology can be applied in most vertically oriented shell and tube exchangers. The fouling prone fluid flows upward inside the tubes, is charged with solid particles that are swept upward with the fluid producing a scouring action on the walls of the tubes as they travel. A unique distribution system in the inlet channel provides a uniform distribution of liquid and particles into all the tubes. From the outlet channel, the particles are carried to the separator where they disengage from the liquid and are returned through the external downcomer into the control channel and from there through the connecting line between control channel and inlet channel into the inlet channel. The flow of particles is activated by the control liquid flow, which is a fraction of the total liquid flow supplied to the exchanger. By changing the control liquid flow, the intensity of the cleaning action can be varied. If desired, the cleaning can also be applied intermittently.

[0021] Preheated tailings stream **115** flows from preheat operation **110** into the drying operation **120**. Make-up steam **150** provides dryer **120** with a part of the enthalpy required by the drying process. As preheated tailings stream **115** is dried, it is separates into two distinct portions, namely, water vapor **180** and solid cake **140**. The water content of the solid cake **140** may be adjusted to the desired end-product composition process requirements, and could range from a pumpable product to a dry cake. The solid cake may comprise insufficient water to flow, which is usually below about 60 mass % water. The water content of the solid cake output could also be between 40 and 60 mass %, or between 0 and 40 mass %. The water vapor **180** is removed from the dryer and commingled with make-up steam **150**. The addition of stream **180** to make-up steam **150** provides the rest of enthalpy requirement for the drying process through condensation in an indirect fashion. Following heat transfer, input steam **150** is condensed and removed from drying operation **120** as condensed water effluent **160**. The condensed water effluent **160** is the result of water vapor **180** released from the tailings **115** and steam introduced to carry out the drying. Condensed water effluent **160** is then used in preheat operation **110**. For example, if the preheat operation employs a heat exchanger, the enthalpy of the condensed water effluent **160** is transferred to tailings stream **100** through the indirect heat transfer between the compartments of the heat exchanger. This has the effect of preheating the tailings stream **100**, raising its temperature and reducing the energy required to carry out the heating in drying operation **120**. Following the indirect heat transfer, much of the enthalpy from condensed water effluent **160** has been passed to the tailings stream, and leaves preheat

operation **110** as high purity water **170**. A significant benefit of this approach in addition to the drying of the tailings, is capturing the originally contaminated water present in the tailings stream as high quality, distilled water. In another embodiment of this invention, the recovered water stream is subsequently used in the extraction process or utilized in an integrated thermal in-situ and mining and extraction operation to generate steam.

[0022] Figure 2 shows an example of the tailings treatment system in accordance with an embodiment of the invention. Tailings stream **200** flows through heat exchanger **210**, for instance at a temperature of approximately 36°C, where it is preheated by condensed water vapor effluent **240**, as discussed above. Suitable temperatures include those below the boiling point of water. As discussed below, a portion of tailings stream **200** may form a bypass stream **295**. The preheated tailings **220** then enter dryer **230**. The tailings are dried with heat energy from input steam **237,** provided by ejector **235**. This steam is a mixture of the water evaporated during drying and make up steam added to the system through ejector **235**. The role of the ejector is to produce slight vacuum inside the dryer **230**, remove the produced water vapor **238**, mix the produced water vapor **238** with make-up steam **236**, and to provide the combined steam at a higher pressure and temperature than the released vapor from tailings. Alternatively, produced steam **238** can be compressed using a compressor, such that minimal or no make-up steam **236** would be required. Dryer **230** is optionally and preferably in an indirect dryer configuration, whereby input steam **237** injected into the dryer is contained within a shell surrounding the dryer cavity, and does not come into direct contact with the tailings. The heat required for drying, therefore, is indirectly transferred from the steam through the shell to the tailings. Input steam **237** loses heat to the preheated tailings, and, as input steam **237** condenses, the tailings will absorb the latent heat of condensation of the water vapor. Any indirectly heated dryer may be used (for example a rotary drum or paddle), but may optionally comprise design features that mix the product and/or scrape the drum walls to minimize thermal resistance. An example of a commercial dryer is the K-S biosolids dryer system for biosolids and biological sludge drying (Komline-Sanderson, Peapack, NJ, U.S.A). An indirect steam dryer is described in U.S. Patent No. 5,291,668. Dryer **230** may comprise one or more dryers, in series or parallel, at least one of which uses indirect steam heating as discussed herein. Other dryer units could use electrical heating for example. The steam used in the dryer could be superheated or at any pressure/temperature required.

[0023] As the preheated tailings **220** are dried, water vapor escapes as produced steam **238**. This steam is substantially free of minerals, as the salts originally contained in the tailings stream remain with the dried solids. Produced steam **238** is piped back and mixed with makeup steam **236**, such that the enthalpy released during the drying operation can be conserved and re-used as the drying operation continues. Hydrocarbons and solvents originating in the preheated tailings stream **220** that are volatilized and subsequently condensed in the condensed water vapor effluent **240**, in addition to the water, can be separated from the recovered water and used at any point in the process. Water-hydrocarbon separations means known in the art may be used (for example oil removal filters, membranes, centrifuges, or separators). For instance, a conventional two-phase separator in stream **240** or **239** could be used. Decantation could also be used to remove hydrocarbon solvents. However, since the condensation of produced steam **238** results in clean, high quality water, one of ordinary skill in the art will appreciate that any water collected therefrom may be put to any variety of uses, including, but not limited to, other phases of the oil sands extraction process. Non-limiting examples of uses for recovered water include boiler feed water for SAGD operations, utility steam, makeup water, etc.

[0024] Streams **239** or **240** may be the equivalent of about 48000 m^3/d of warm or hot water. This water may be used in bitumen extraction to significantly reduce the fresh water requirements of a conventional bitumen mining and extraction operation, by about half, for instance. Alternatively, it may be used in a SAGD operation to supply more than the necessary boiler feed water (BFW) in a 20,000 bbl/d to 30,000bbl/d thermal in-situ operation that may be adjacent to the mining/extraction operation. The recovery of this water is an alternative method to make BFW from process affected water.

[0025] According to one embodiment of the invention, input steam **237** has temperature and pressure from ejector **235** of 103°C and 113 KPa, respectively. The input steam should be at a sufficiently higher temperature than both the inlet tailings temperature and boiling point of water at the cavity operating pressure to transfer heat across the dryer wall at the desired rate. Optionally and preferably, ejector **235** also creates a low-pressure environment, for instance below atmospheric pressure, within the cavity of dryer **230**, such that the boiling point of water is reduced, leading to a lower temperature of the dried tailings. The ejector controls pressure in the dryer cavity and in the dryer shell using makeup steam **236** as a motive fluid. The pressure in the dryer cavity may be reduced to any practical limit. Parameters that set the limit are in part based on make up steam **236** pressure, ejector

pressure ratio, mass flow rate ratio between make-up steam **236** and produced steam **238** This lowers the boiling point of water within the cavity, and the water contained within the tailings will consequently undergo a phase change to a gaseous state at a lower temperature and pressure. In this manner, the ejector can serve two functions: raise the pressure of produced steam stream **238** so that it can be introduced to dryer **230** at a higher temperature, and lower the pressure in the cavity of dryer **230** so that tailings water will evaporate at a lower temperature.

[0026] As it condenses, input steam **237** leaves dryer **230** as condensed water effluent **240**, at a temperature of approximately 83°C, or higher than the tailings temperature in accordance with this example. Condensed water vapor effluent **240** then flows through a second compartment of heat exchanger **210** and, through indirect heat transfer, preheats the tailings stream **200** currently flowing through the first compartment. During normal operation of this embodiment of the invention, sufficient sensible heat is transferred from condensed water effluent **240** to the tailings stream **200**, such that the temperature of the tailings increases from 36°C to 55°C, thereby greatly reducing the energy required by dryer **230** to dry the preheated tailings. Following preheat, the condensed water vapor effluent **240** leaves heat exchanger **210** as liquid water at a temperature of 60°C. The recovered water **239** may then be collected and used in the extraction process or to make boiler feed water for steam generation in an integrated thermal in-situ and mining/extraction operation. Higher throughput may also be achieved where less than the full amount of steam is condensed in the dryer, but a portion of the steam is condensed in the heat exchanger **210**. Optionally, the preheat heat exchanger may be eliminated, by increasing the length or surface area of the dryer such that condensed water vapor effluent **240** leaves the dryer at about 60°C.

[0027] A further aspect of the present invention provides for converting a tailings stream to dry, stackable tailings that can be disposed of through, for example, direct mine refill, water capping, overburden capping, capping with consolidated tailings, or sand layering. An output of the drying operation is solid cake **250**, which comprises dried clay, sand, residual hydrocarbons and other mineral deposits from the tailings. Because solid cake **250** has been separated from much of the water originally contained in tailings stream **200**, the overall volume of tailings to be disposed is significantly reduced and thus reduces the footprint of the tailings pond. Optionally, the solid cake is mixed with bypass stream **295**, which is some portion of untreated tailings stream **200,** for instance 5 to 20%, or about 10% in this example. The bypass stream assists in processing a larger volume of tailings and

produces a pumpable material so that expensive trucks or conveyors are not required. To make the tailings particularly suitable to backfill, the moisture content should range from 0 – 40%, preferably between 10 – 20%. This final mixing step is carried out by mixer **280** and results in thickened tailings **290**, which is composed of a substantial portion of solids tailing material, for instance approximately 75% solid tailings material. Thickened tailings **290** can then be disposed of in any desired manner, although they are particularly suitable for "back fill," or refilling the oil sands mine from which the original unprocessed bitumen was extracted.

[0028] According to one embodiment of the invention, solid cake **250** is divided into two parts: solid cake remainder **270** and recycled solid stream **260**. Solid cake remainder **270** then undergoes the optional mixing treatment discussed above, followed by disposal. Recycled solid stream **260**, which in this example is approximately 50% of solid cake **250**, is piped back and mixed with preheated tailings **220** as the drying operation continues. This increases the solid content of the dryer's feed, thereby reducing fouling within the dryer itself Approximately 50% of solid cake **250**, is piped back and mixed with preheated tailings **220** to increase the solid content of the dryer feed to an acceptable level (for example over 35%). In this example, the solid content of the dryer's feed was increased to approximately 37% by combining with the recycle stream. As the solid content increases, materials become less sticky in the dryer, which is an advantage in a high temperature operation.

[0029] Figure 3 shows another embodiment of the present invention, whereby a tailings stream undergoes two separate preheat operations to further improve the efficiency of the treatment process. Elements common between this embodiment and the exemplary embodiments previously discussed are marked in Figure 3 with labels matching those in previous figures, and function as described above.

[0030] Tailings stream **300** enters a first heat exchanger **301**, which functions according to the same principles described above with reference to heat exchanger **210**. As discussed above, the heat exchangers are optionally and preferably self-cleaning heat exchangers to minimize fouling. First, heat exchanger **301** receives hot flue gas **305** and uses it as the heat source to initially preheat tailings stream **300.** Flue gas **305** (optionally and preferably with minimal sulfur content) may be sourced from any other step in the oil sands extraction process or an integrated thermal in-situ operation that produces a gas capable of flowing through first heat exchanger **301** and providing heat energy to tailings stream **300**, such as from a boiler. Optionally and preferably, flue gas **305** passes through

fan **310**, which serves to increase the pressure inside first heat exchanger **301**, because flue gas is at atmospheric pressure, and should be increased to account for the pressure drop within exchanger **301**. Fan **310** may also be a compressor. In one example of the embodiment shown in Figure 3, tailings **300** enter heat exchanger **301** at a temperature of 36°C. Flue gas **305** is at a temperature of approximately 150°C, and provides sufficient heat to the tailings in first heat exchanger **301** so as to increase the temperature of the tailings to 60°C. An induced fan could be used to pull the flue gas through the heat exchanger. This would be positioned on stream **313** and has the benefit of handling a lower temperature, higher density gas.

[0031] Following the first preheat operation, the cooled flue gas and any condensed water vapour **306** from first heat exchanger **301** is collected and separated in separator **311**. This allows the system to recover additional water, as flue gas **305** may contain significant water content. The water content of cooled flue gas **306** is collected from separator **311** as condensed liquid **312**, which, if desired, may be added to water **239** (discussed above with reference to Figure 2), thereby becoming part of the total water recovered from the tailings treatment process, or become feed for another process. The remaining components of cooled flue gas **306** are released from separator **311** as separator flue gas **313**.

[0032] The tailings preheated during the first preheat operation leave first heat exchanger **301** as initially preheated tailings **302**. These tailings may then undergo a second preheat operation in heat exchanger **210**, which transfers heat to initially preheated tailings **302** from condensed water vapor effluent **240** as discussed above with reference to Figure 2. The remaining elements shown in Figure 3 function in the same manner as the corresponding elements shown in Figure 2, and the elements in Figure 3 are consequently labeled with identical identifiers for ease of reference to the discussion above. In particular, a bypass stream **295** is taken from the tailings stream **300** and mixed with solid cake remainder **270** by mixer **280** to form thickened tailings output **290**. Preheated tailings **220** are fed to dryer **230** and are at, according to this example, approximately 90°C. Condensed water vapor effluent **240** from dryer **230** is fed into heat exchanger **210** at approximately 99°C in this example. Produced steam **238** released from the dryer **230** is mixed with makeup steam **236** to form input steam **237** which is introduced into dryer **230** by ejector **235**. Solid cake **250** exits the dryer once the drying operation is complete. Optionally and preferably, a portion of solid cake **250** is separated and sent as recycled solid stream **260** to mix with preheated tailings **220** to help reduce fouling inside the dryer.

[0033] The embodiments of the invention that include two distinct preheat steps may provide even greater efficiency to the overall tailings treatment process, as enthalpy from flue gas **305** which might otherwise be lost is instead transferred to the tailings stream, thereby further reducing the heat energy required by dryer **230**. In addition, water contained in the flue gas **305** which might otherwise be lost is instead at least partially collected by separator **311**, and forms part of the total water collected during the treatment process. However, as one of ordinary skill in the art will appreciate, flue gas **305** may be sourced from another industrial or extraction process and still function in accordance with embodiments of the invention.

[0034] In accordance with another embodiment of the invention, valuable heavy minerals can be recovered from oil sand tailings. Heavy minerals are defined herein as minerals having a specific gravity greater than about 2.85, and including, without being limited to, such minerals as rutile, ilmenite, leucoxene, siderite, anatase, pyrite, zircon, tourmaline, garnet, magnetite, manzite, kyanite, staurolite, mica, and chlorite. Material extracted from oil sands often includes deposits of usable heavy minerals such as titanium and zirconium. In order to recover usable resources from the material, solid cake **250** may also be subjected to a heavy minerals recovery step. Several non-limiting examples include gravity, electrostatic, chemical, and magnetic separation techniques, although another suitable method for extracting heavy minerals from a solid cake may be used for this purpose. This step allows for recovery of additional valuable resources from treated tailings, further improving the recovery of valuable resources during oil sands extraction, thereby making the entire process more economically viable and reducing the amount of waste material that must be disposed of. It should be noted that heavy metal recovery or another separation process (such as coarse solid removal using a separation device) may be employed at any point in the tailings treatments as additional embodiments of the present invention.

[0035] Several other advantages of treating tailings streams through drying in accordance with the present invention may include, but are not limited to: recovering extraction process water as high-quality warm water; achieving a net gain in sensible heat by an appropriate heat integration scheme; producing dry, stackable tailings, thereby reducing dykes in current tailings treatment and reducing the overall volume of tailings that must be disposed of; reducing the footprint of oil sands extraction, and allowing for the potential recovery of valuable heavy metal oxides, such as titanium and zirconium oxides.

[0036] **Example**

[0037] With reference to Figures 2 and 3, Table 1 provides flow rates and temperatures, according to one embodiment, for certain streams identified by their reference numbers.

[0038] Table 1. Flow rates and Temperatures

Reference number (stream)	Flow rate tons per hour	Temperature (°C)
Figure 2		
200	2820	36
220	2540	55
236	100	147
240	2055	83
270	580	95
290	865	75
295	280	36
239	2055	60
Figure 3		
220	2540	90
236	12.5	147
239	1950	64
240	1950	99
300	2820	36
302	2540	60
305	1100	150
313	1030	40
239 and 312 together	2035	63

[0039] In the preceding description, for purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the embodiments of the invention. However, it will be apparent to one skilled in the art that these specific details are not required in order to practice the invention.

[0040] The above-described embodiments of the invention are intended to be examples only. Alterations, modifications and variations can be effected to the particular embodiments by those of skill in the art without departing from the scope of the invention, which is defined solely by the claims appended hereto.

CLAIMS:

1. A method for treating a tailings stream produced during extraction of bitumen from oil sands, comprising:

drying the tailings stream in a dryer using input steam in indirect thermal contact with the tailings stream to produce a dried tailings stream, whereby the input steam converts to a condensed water effluent; and

recycling steam produced from the dryer back into the dryer, wherein the input steam comprises (i) the recycled steam and make-up steam, or (ii) the recycled steam passed through a compressor, and optionally make-up steam.

2. The method of claim 1, further comprising, prior to drying the tailings stream, introducing the tailings stream into a heat exchanger to preheat the tailings stream and produce a preheated tailings stream which is then fed into the dryer.

3. The method of claim 2, wherein the preheating in the heat exchanger is by indirect contact with the condensed water effluent which is passed from the dryer.

4. The method of claim 2 or 3, wherein the heat exchanger is a self-cleaning heat exchanger.

5. The method of any one of claims 1 to 4, wherein the input steam comprises the recycled steam and the make-up steam.

6. The method of any one of claims 1 to 5, wherein the tailings stream comprises at least one of the following: coarse tailings, fine tailings, froth separation tailings, and tailings solvent recovery unit tailings.

7. The method of claim 6, wherein the fine tailings comprise a middling stream, flotation tailings, or mature fine tailings.

8. The method of any one of claims 1 to 7, further comprising increasing a solid content of the tailings stream fed to the dryer by introducing a portion of the dried tailings stream into the tailings stream.

9. The method of any one of claims 1 to 8, wherein the step of drying the tailings stream is carried out below atmospheric pressure, such that the boiling point of water is reduced, leading to a lower temperature of the dried tailings.

10. The method of claim 9, wherein the dryer pressure is controlled by an ejector, the ejector also serving to remove produced steam from the dryer, and to mix the steam produced from the dryer with make-up steam.

11. The method of claim 1, wherein the input steam comprises a combination of recycled steam and make-up steam passed through the compressor.

12. The method of any one of claims 1 to 11, further comprising recovering at least one heavy mineral from the dried tailings stream.

13. The method of claim 12, wherein the at least one heavy mineral comprises zirconium oxide or titanium oxide.

14. The method of any one of claims 1 to 13, further comprising mixing the dried tailings with a bypass stream of untreated tailings.

15. The method of any one of claims 1 to 14, wherein the condensed water effluent from the dryer is processed in a separation step to recover condensed hydrocarbons.

16. A system for treating a tailings stream produced during extraction of bitumen from oil sands, comprising:

a dryer for receiving the tailings stream and input steam, drying the tailings stream using heat from the input steam, and producing a condensed water effluent; and

a steam recycling unit for recycling steam produced from the dryer back into the dryer, wherein the input steam comprises (i) the recycled steam and make-up steam, or (ii) the recycled steam passed through a compressor, and optionally make-up steam.

17. The system of claim 16, further comprising a heat exchanger for receiving the tailings stream and the condensed water effluent from the dryer in indirect thermal contact with one another, and preheating the tailings stream using heat from the condensed water effluent, prior to drying.

18. The system of claim 16 or 17, further comprising an ejector for providing the input steam.

19. The system of claim 18, wherein the ejector is also for controlling a pressure environment in the dryer.

20. The system of any one of claim 16 to 19, wherein the input steam comprises steam removed from the dryer and passed through a compressor, with make-up steam as required.

21. The system of claim 20, wherein the make-up steam is combined with the steam removed from the dryer before the compressor.

22. The system of claim 20, wherein the make-up steam is combined with the steam removed from the dryer after the compressor.

23. The system of any one of claims 16 to 22, wherein the dryer comprises a shell for receiving the input steam and a cavity for receiving the preheated tailings stream, the shell and the cavity being distinct compartments in thermal communication with one another.

24. The system of any one of claims 16 to 23, further comprising a mixer for adding a bypass stream of untreated tailings to dried tailings exiting the dryer.

25. A method for treating a tailings stream produced during extraction of bitumen from oil sands, comprising:

a) introducing the tailings stream and a flue gas into a first heat exchanger to preheat the tailings stream,

b) introducing the tailings stream into a second heat exchanger to preheat the tailing stream, wherein step a) is performed before step b) or step b) is performed before step a), to produce a preheated tailings stream,

c) drying the preheated tailings stream in a dryer using input steam in indirect thermal contact with the preheated tailings stream to produce a dried tailings stream, whereby the input steam converts to a condensed water effluent,

d) recycling steam produced from the dryer back into the dryer, wherein the input steam comprises (i) the recycled steam and make-up steam, or (ii) the recycled steam passed through a compressor, and optionally make-up steam; and

e) passing the condensed water effluent from the dryer to the second heat exchanger to preheat the tailings stream.

26. The method of claim 25, wherein the tailings stream comprises at least one of the following: coarse tailings, fine tailings, mature fine tailings, froth separation tailings, and tailings solvent recovery unit tailings.

27. The method of claim 26, wherein the fine tailings comprises a middling stream, flotation tailings, or mature fine tailings.

28. The method of any one of claims 25 to 27, wherein the flue gas is sourced from a steam generator, bitumen extraction process, or a bitumen processing step.

29. The method of claim 28, further comprising introducing the flue gas into a fan or a compressor for increasing the pressure of the flue gas.

30. The method of any one of claims 25 to 29, further comprising condensing water in the flue gas in the first heat exchanger and separating the condensed water from the flue gas in a separator.

31. The method of any one of claims 25 to 30, wherein the input steam comprises the recycle steam and make-up steam.

32. The method of any one of claims 25 to 30 wherein at least one of the first heat exchanger and the second heat exchanger is a self-cleaning heat exchanger.

33. The method of any one of claims 25 to 32, further comprising increasing a solid content of the preheated tailings stream by introducing a portion of the dried tailings stream into the preheated tailings stream to mitigate fouling in the dryer and to increase efficiency in the dryer.

34. The method of any one of claims 25 to 33, wherein drying the preheated tailings stream in the dryer is carried out below atmospheric pressure.

35. The method of any one of claims 25 to 34, wherein pressure in the dryer is controlled by an ejector or the compressor.

36. The method of any one of claims 25 to 35, further comprising recovering at least one heavy mineral from the dried tailings stream.

37. The method of claim 36, wherein the at least one heavy mineral comprises zirconium or titanium oxides.

38. The method of any one of claims 25 to 37, further comprising mixing the dried tailings with a bypass stream of untreated tailings.

39. A system for treating a tailings stream produced during extraction of bitumen from oil sands, comprising:

a first heat exchanger for receiving the tailings stream and a flue gas, and preheating the tailings stream using heat from the flue gas;

a second heat exchanger for receiving the tailings stream and a condensed water effluent and preheating the tailings stream using heat from the condensed water effluent, wherein the first or the second heat exchanger is placed upstream of the other;

a dryer for receiving the preheated tailings stream and input steam, heating the preheated tailings stream using heat from the input steam to produce a dried tailings stream, and producing the condensed water effluent used in the second heat exchanger; and

a steam recycling unit for recycling steam produced from the dryer back into the dryer, wherein the input steam comprises (i) the recycled steam and make-up steam, or (ii) the recycled steam passed through a compressor, and optionally make-up steam.

40. The system of claim 39, wherein the flue gas is sourced from a steam generator, bitumen extraction processor, or a bitumen processing step.

41. The system of claim 39, further comprising a fan or a compressor for increasing the pressure of the flue gas.

42. The system of claim 39, further comprising a separator for separating condensed water that has condensed in the first heat exchanger from the flue gas.

43. The system of claim 39, further comprising an ejector for providing the input steam and receiving steam released from the preheated tailings stream in the dryer.

44. The system of claim 43, wherein the ejector is also for controlling a pressure environment in the dryer.

45. The system of any one of claims 39 to 44, wherein the input steam comprises the recycled steam and the make-up steam.

46. The system of any one of claims 39 to 45, wherein the dryer comprises a shell for receiving the input steam and a cavity for receiving the preheated tailings stream, the shell and the cavity being distinct compartments in thermal communication with one another.

47. The system of any one of claims 39 to 46, further comprising a mixer for adding a bypass stream of untreated tailings to the dried tailings stream exiting the dryer.

48. The method of any one of claims 2 to 4, and 25 to 38, wherein water passed through the second heat exchanger to preheat the tailings stream is reused in a bitumen extraction operation.

49. The method of any one of claims 2 to 4, and 25 to 38, wherein water passed through the second heat exchanger to preheat the tailings stream is used in a thermal bitumen production operation as boiler feed water.

50. The system of any one of claims 16 to 24, and 39 to 47, wherein the dryer comprises one or more dryers, in series on in parallel, at least one of which uses indirect steam heating

51. The system of claim 50, wherein another of the one or more dryers uses electrical heating.

52. The method of any one of claims 1 to 15 and 25 to 38, wherein the input steam is superheated.

53. The method of any one of claims 1 to 15, and 25 to 38, wherein the dried tailings stream has a water content of below 60 percent by mass.

54. The method of any one of claims 1 to 15, and 25 to 38, wherein the dried tailings stream has a water content of 40 to 60 percent by mass.

55. The method of any one of claims 1 to 15, and 25 to 38, wherein the dried tailings stream has a water content of 0 to 40 percent by mass.

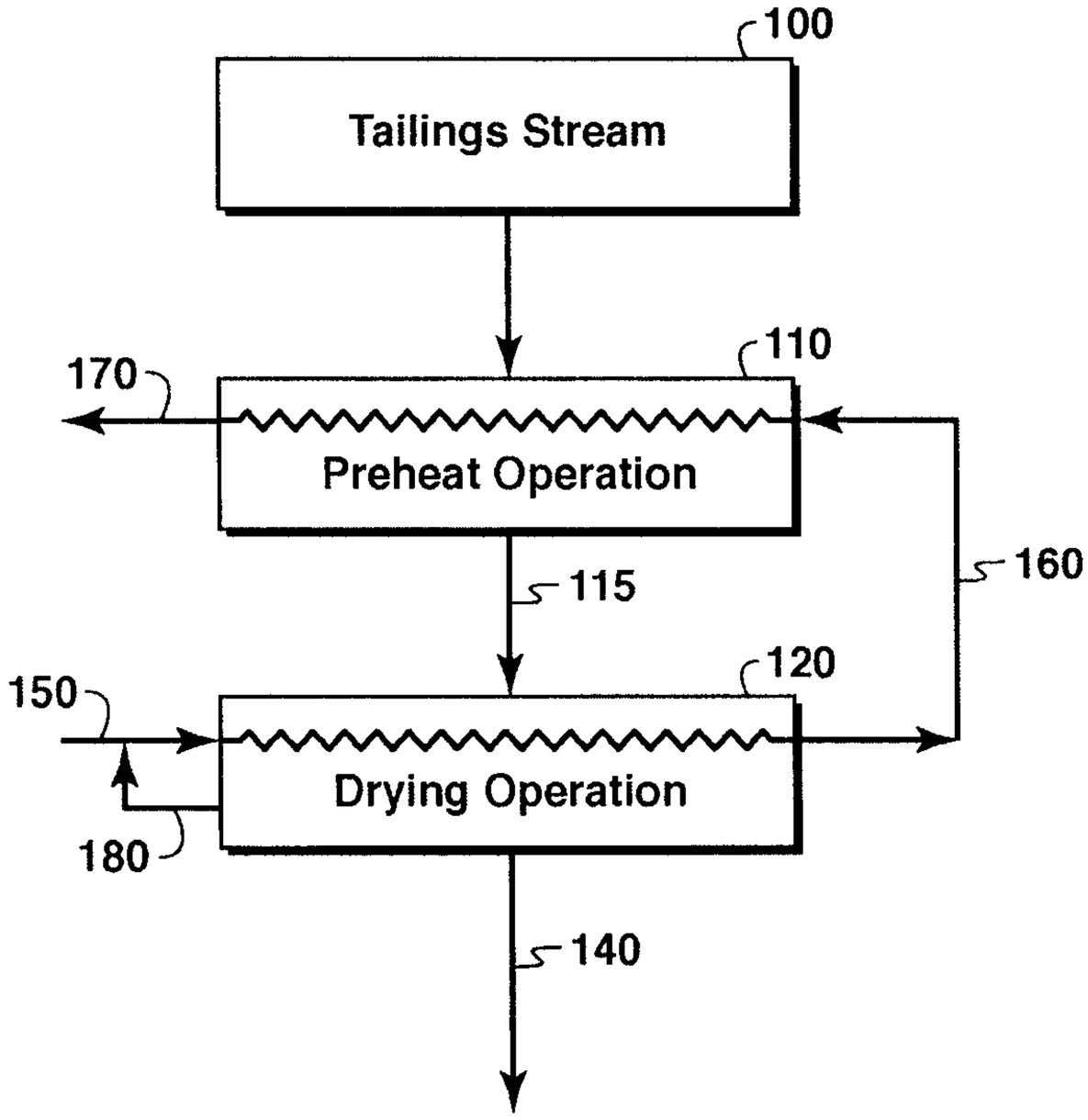

100
Tailings Stream
110
170
Preheat Operation
160
115
120
150
Drying Operation
180
140

FIG. 1

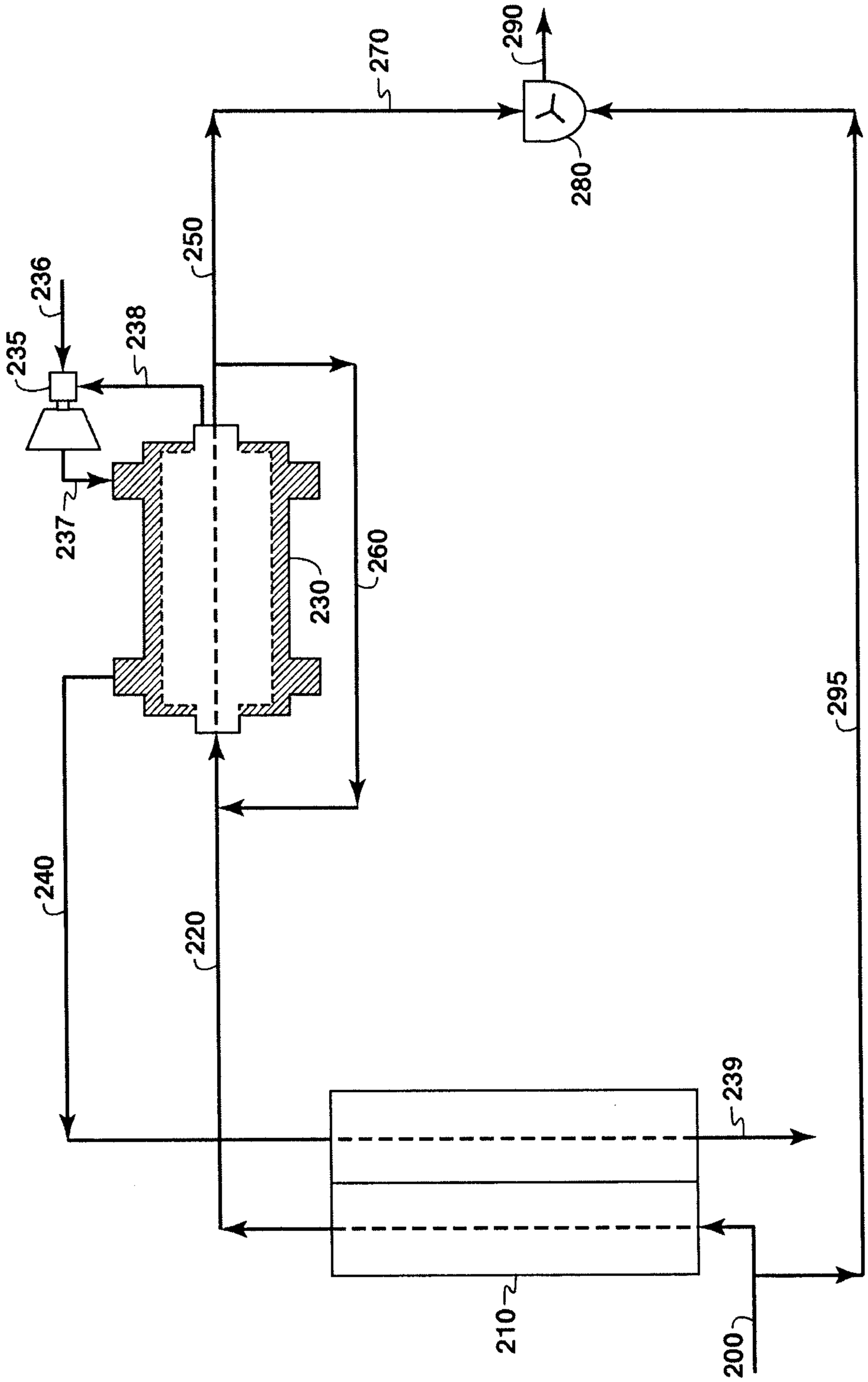


FIG. 2

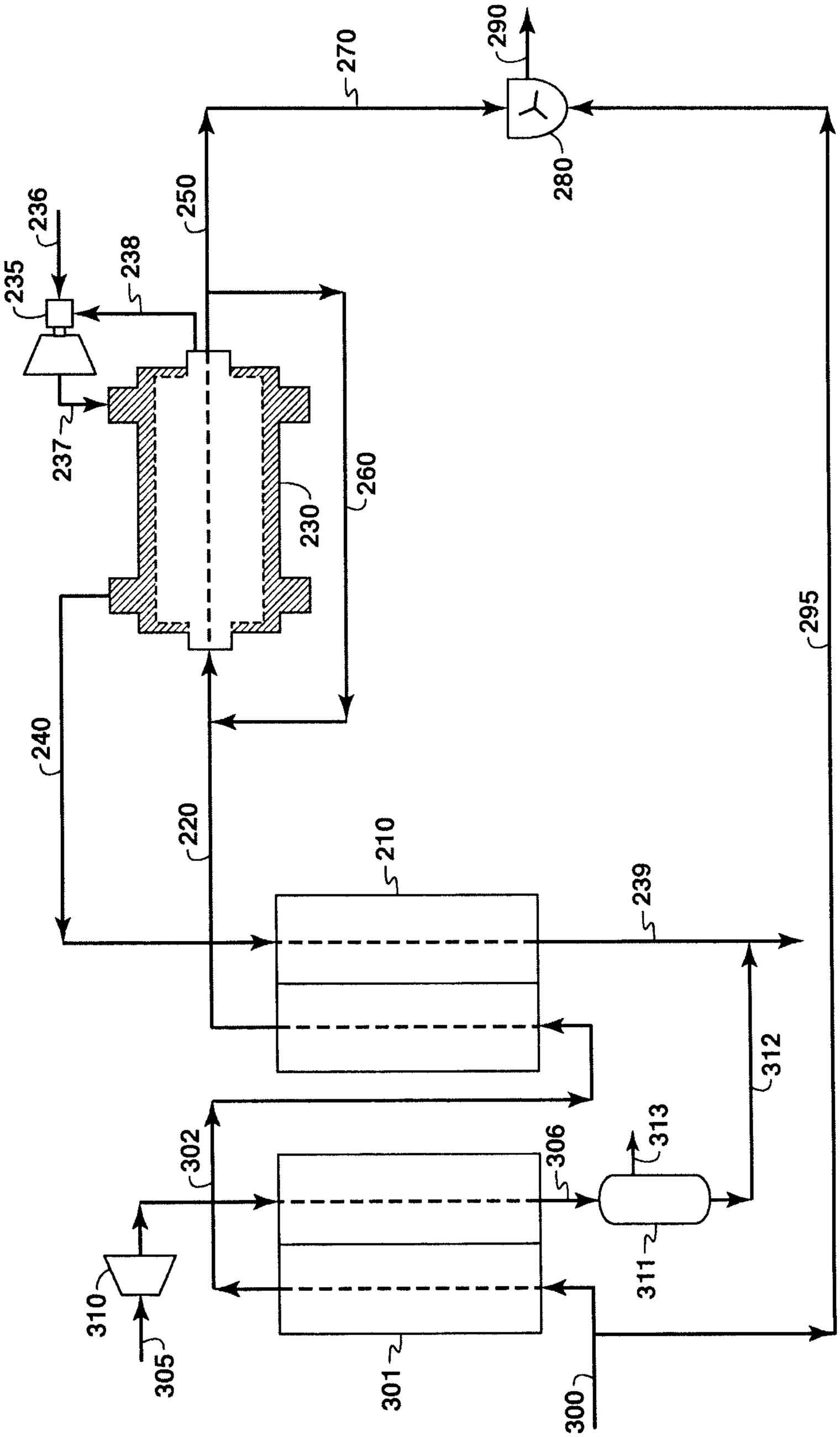
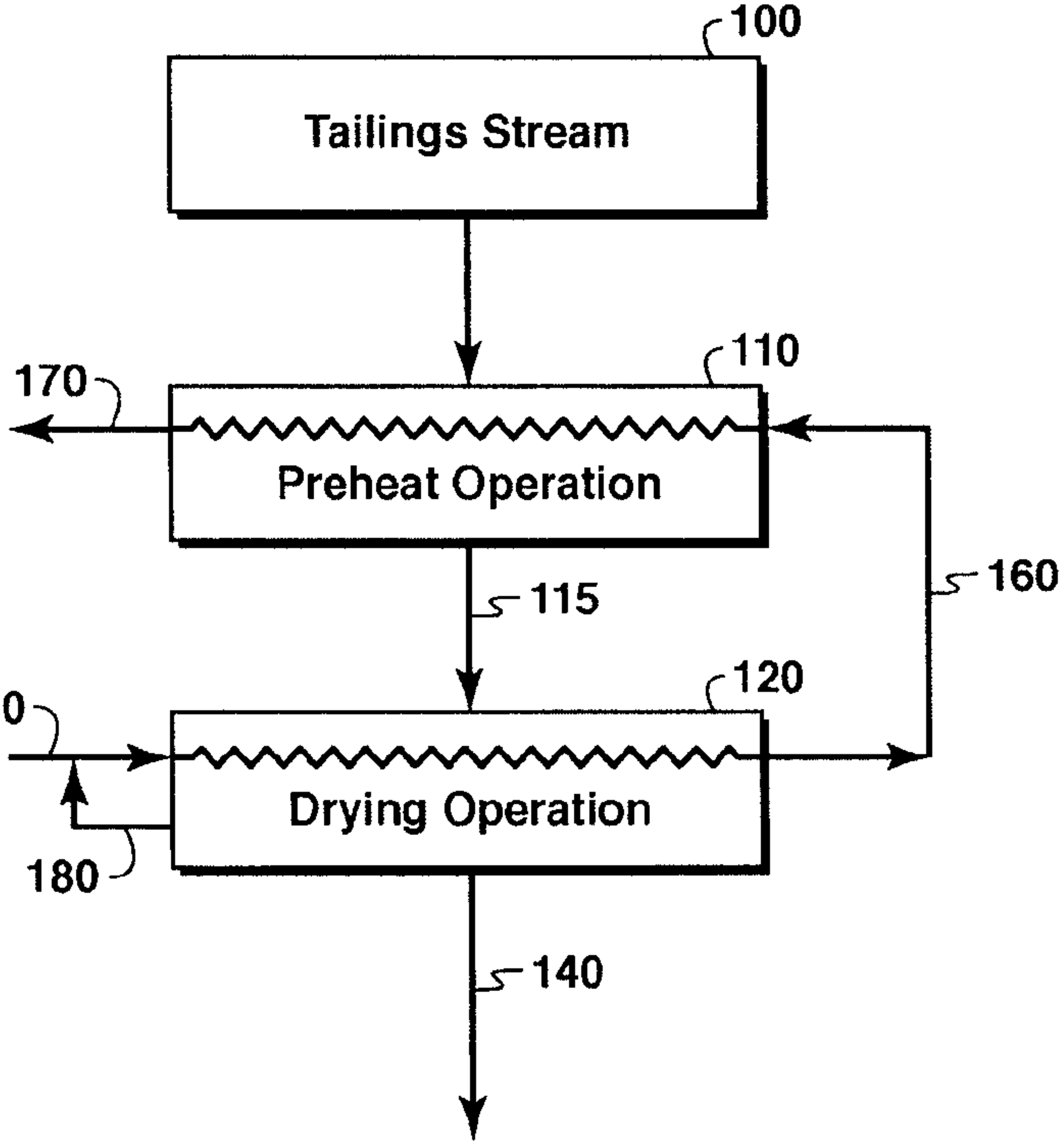

270
290
280
295
250
236
235
238
237
260
230
240
220
210
239
312
313
302
306
310
305
311
301
300

FIG. 3


100
Tailings Stream
110
170
Preheat Operation
115
160
120
150
Drying Operation
180
140