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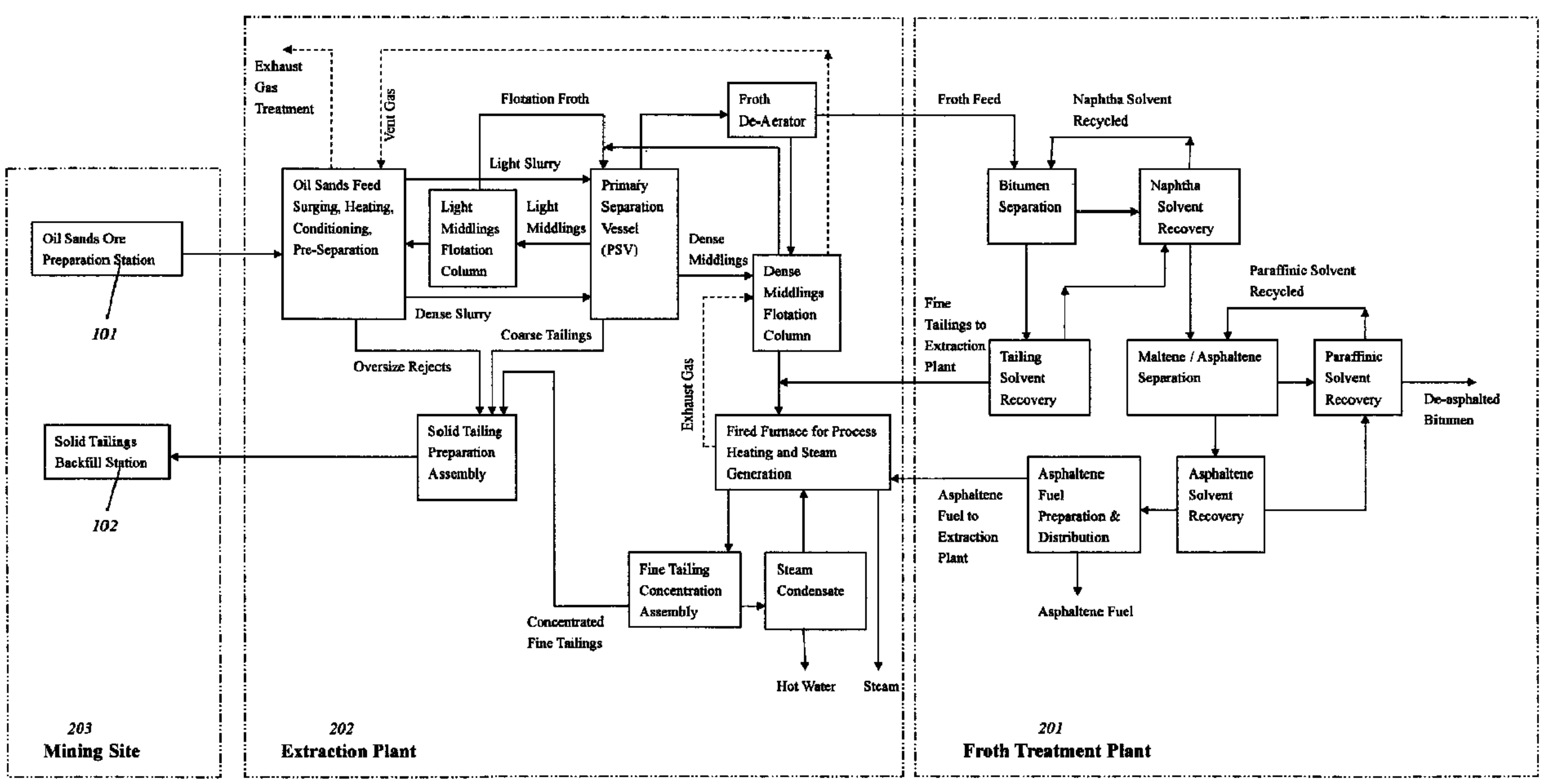
(54) Titre : SYSTEME INTEGRE PERMETTANT LA PRODUCTION DE BITUME DESASPHALTE A PARTIR DE SABLES BITUMINEUX

(54) Title: AN INTEGRATED SYSTEM FOR PRODUCING DE-ASPHALTED BITUMEN FROM OIL SANDS



Overall Process Flow Diagram of the Integrated System

(57) Abrégé/Abstract:
An integrated system for producing de-asphalted bitumen from oil sands, comprising the following sub-systems: using pneumatic capsule pipeline to transport oil sands from mining site to extraction plant for bitumen extraction and solid tailings from extraction plant to mining site for backfill, using a compact assembly of oil sands heating, conditioning, and primary separation to enhance separation efficiency, using a thermal cycle of evaporation and condensation in a heat exchanger to concentrate fine tailings and recover steam condensate, using a de-watering assembly to recover water from coarse tailings, combining de-watered coarse tailings and concentrated fine tailings to form solid tailings for backfill, employing a process to produce de-asphalted bitumen and asphaltenes from bitumen froth, using aspaltenes separated from bitumen froth to prepare asphaltene-based fuel, using asphaltene fuel prepared in the system to fuel the system, and using process streams to treat the exhaust gas generated from asphaltene fuel combustion.

ABSTRACT

An integrated system for producing de-asphalted bitumen from oil sands, comprising the following sub-systems: using pneumatic capsule pipeline to transport oil sands from mining site to extraction plant for bitumen extraction and solid tailings from extraction plant to mining site for backfill, using a compact assembly of oil sands heating, conditioning, and primary separation to enhance separation efficiency, using a thermal cycle of evaporation and condensation in a heat exchanger to concentrate fine tailings and recover steam condensate, using a de-watering assembly to recover water from coarse tailings, combining de-watered coarse tailings and concentrated fine tailings to form solid tailings for backfill, employing a process to produce de-asphalted bitumen and asphaltenes from bitumen froth, using aspaltenes separated from bitumen froth to prepare asphaltene-based fuel, using asphaltene fuel prepared in the system to fuel the system, and using process streams to treat the exhaust gas generated from asphaltene fuel combustion.

DESCRIPTION

FIELD OF THE INVENTION

This invention relates to an integrated system and apparatus for producing de-asphalted bitumen from oil sands. More specifically it relates to pneumatic transport and conveying of oil sands and solid tailings, a compact assembly for oil sands surging, heating, conditioning, and primary separation, a compact assembly for fine tailings concentration and steam condensate production, a process for solid tailings preparation and backfill, a process for bitumen froth treatment to produce de-asphalted bitumen and asphaltene-based fuel.

BACKGROUND OF THE INVENTION

The Athabasca oil sands deposits in North Alberta, Canada contains an estimated 1.3 trillion barrels of recoverable bitumen which represents a significant portion of the worldwide reserves of conventional and non-conventional oil reserves, the bitumen production from oil sands in Alberta is becoming one of the most important energy sources around the world. However, the bitumen produced from oil sands is called 'dirty oil' because the oil sands industry currently not only produces synthetic crude oil (SCO) for refineries, but also consumes a large amount of other natural resources, including natural gas and fresh water, at the same time, creates severe damages to the environment, such as tailing pond issues, landscape changes, waste solid storage issues, greenhouse gas (GHG) emissions and eco-system changes. There is an urgent demand for the industry to innovate new processes to meet the requirements of sustainable social and economical development as well as environmental protection.

Oil sand by definition is a mixture of mainly silica sand grains banded with bitumen, water, and minor amount of clay and silt. The silica sand grains form a dense interlocked skeleton, the pore spaces of the skeleton are occupied partially by bitumen and water, and clay and silt are dispersed in the sticky mixture of bitumen and water. In the Athabasca oil sands deposits the sand grains are whetted by water, the bitumen is isolated from the sand grains by a layer of water.

The bitumen content varies from about 5% to 21% by weight, with a typical content of about 10% to 12% by weight, and the in-situ bitumen at natural reservoir conditions is quite viscous with a semi-solid form that causes the oil sands to be relatively impermeable to the flow of free water and gas.

In the Athabasca oil sands deposits the oil sands formation is tilted from the surface of the ground to depths of about 600 meters below overburden. When oil sands deposits are at or near the surface, they can be recovered by surface mining methods. Recovery by surface mining is economical when there is a relatively thin layer of overburden that can be removed by large surface excavation machines. The open-pit mining method is widely employed in current oil sands industry, the bitumen recovery is about 95% in extraction plant, 98% in froth treatment plant, and 95% in upgrader, and the total bitumen recovery can be up to 89% for the synthetic crude oil. However, it is estimated that less than 20% of the oil sands reserves in Alberta is suitable for surface mining. When oil sands deposits are too far below the surface for economical recovery by surface mining, bitumen can be economically recovered in many special areas by in-situ recovery methods, currently known as steam assisted gravity drain (SAGD) or other variants of gravity drain technology which can mobilize the bitumen by steam heating and collect the flowing bitumen through conventional crude oil production. The bitumen recovery of in-situ processes is usually less than 60%, mostly depending on the geological conditions. Recent commercial practices indicate the bitumen production of SAGD is hard to reach the designed capacity, which means more than 40% bitumen in the formation will be left underground, and cannot be used in the future.

It is also estimated that about 65% of the Athabasca oil sands deposits (approximately 845 billion barrels) cannot be recovered by either surface mining or in-situ technologies because of a considerable portion of oil sands deposits located in the so-called "no man's land". Three types of the "no man's land" were featured: (1) there are too thick overburden or too much water-laden muskeg above the oil sands deposits to achieve economical recovery by surface mining operations; (2) the overburden is too thin for in-situ thermal recovery processes to be applied effectively; or (3) the oil sands deposits are too thin (typically less than 20 meters thick) for efficient use of both surface mining and in-situ methods. The economical grade bitumen in these "no man's land" areas ranges from 30 to 100 billion barrels, and there is currently no viable means to recover the bitumen from these "no man's land" areas. Therefore, there are great potentials to develop underground mining methods to extract bitumen from these types of oil sands deposits.

In current state-of-the-art oil sands surface mines, the exposed oil sands are excavated directly by large power shovels, transported by large haulage trucks to ore preparation plant where the ore is crushed and turned into slurry. From there, the slurry is hydrotransported to extraction plant where bitumen froth is separated from the slurry. The bitumen froth recovered from the extraction process is then transported to froth treatment plant where diluted bitumen is separated from the bitumen froth, finally the diluted bitumen is transported to upgrader where it is refined and converted into synthetic crude oil (SCO) for downstream refineries.

In the large surface mining process described above, there is substantial disturbance of the surface. In Canada especially, the disturbed surface must be returned to its original condition after the recovery operations are complete. This requirement adds significantly to overall bitumen recovery costs. In the large surface mines, excavating the material and extracting the bitumen contribute significant emissions (principally carbon dioxide and methane) to the atmosphere. On the other hand, once the bitumen has been extracted, the volume of tailings is actually greater than the original volume. This is because the bitumen originally resides in the pore space of interlocked sand grains. Even with the bitumen removed, the sand grains cannot be reconstituted into their original volume even under tremendous pressure. Thus, current surface mining methods result in a large and costly tailings disposal problem.

In current commercial surface mining process, the as-mined ore is trucked from the mining site to the ore preparation plant next to the central extraction plant, the haulage rate could be up to 10,000 t/h. Over time, the mine faces moved further from the central extraction plant. New mines were also opened that were distant (for example, 25 kilo-meters away), both trucks and belt conveyors were expensive and difficult to operate with reliability required over the long distance transportation. The transportation and maintenance cost for the massive solids transfer is a big concern. The recent disclosure of mobile conveying system and semi-mobile slurrying system partially solves the massive solid transportation issue, however, the method does not reduce the volume and the distance of the solid stream to be processed, rather than convert the solid stream into a slurry stream, to reduce the cost of trucking and belt conveying. The long distance of the slurry hydrotransport line may raise new issues, including slurry over conditioning that results in an increase of fines in middlings, slurry line rotation and other maintenance, and a higher mechanical energy consumption.

The commercial extraction process for recovery of bitumen from oil sands is based on the Clark hot water extraction process (CHWEP). The process uses vigorous mechanical agitation of the oil sands with water and caustic alkali to disrupt the granules and form a slurry, after which the slurry is passed to a separation tank for the flotation of the bitumen from which the bitumen is skimmed. As mentioned above, a central extraction plant has to have a very large capacity to meet the economical requirement, as a result, the size of equipment used in the plant, such as primary separation vessel (PSV), may be up to 40 meters in diameter, and fine tailings thickener, may be up to 110 meters in diameter, both of them are based on the gravitational settling principle, the capital cost of these types of equipment is very high, the plant site is big, and the facility cannot be moveable. On the other hand, the current technologies for tailing treatment cannot meet the requirements for environmental protection and water recovery, as well as land reclamation, although the low energy extraction process (LEE) has achieved a significant energy saving. The tailing pond will remain as one of the top priority issues.

There are a number of attempts to improve the conditioning of oil sand slurry, including adding thermal energy and mechanical energy, adjusting chemical environment with caustic and emulsifier. Earlier methods, such as the Clark process, used temperatures of 85 degree C and above together with vigorous mechanical agitation and are highly energy inefficient. It is characteristic of the above process that a great deal of heat and mechanical energy is expended on physically disintegrating the oil sands structure and placing the resulting material in fluid suspension, this disintegration being followed by physical separation of the constituents of the suspension. Chemical adjuvants, particularly alkalis, are utilized to assist these processes. These measures are really useful for the improvement of bitumen recovery. But there is a dilemma. With the bitumen recovery increase, fine clay-constituting particles are dispersed as a gel network, into the middlings stream during the process, these gel-like fines limit the degree to which the water utilized in the process can be recovered by flocculation of the clay particles. No economical means has been discovered of disposing of the flocculated and thickened clay particles, which form a sludge which must be stored in sludge ponds where it remains in a gel-like state indefinitely, and brings a large net input of thermal energy and unrecoverable water, as a result, the serious environmental issues mentioned before. This causes the major difficulty of the surface mined oil sands processing industry currently.

Some compromises have been taken to improve the conditioning of oil sands. The LEE process uses a 2 kilo-meter long hydrotransport line combined with aeration operation to strengthen the mechanical disintegration of bitumen from oil sand grains and enhance the formation of aerated bitumen bubbles, while reducing the thermal and chemical effects at lower temperatures and eliminating caustic aids. The BitMin process uses a gently rotating drum with a spiral and advancing plates in it to wash oil sands at moderate temperatures to avoid disaggregating of the clay content in oil sands. Canadian Patent 2,124,199 relies mainly on thermal action alone to provide release or liberation of the bitumen. The presence of hot water acts as a medium both for heat transfer and for separation to occur. Mechanical action is used to ensure adequate contact between the water and the oil sand and its separated constituents so as to permit it to act effectively as both a heat transfer medium and a separation medium. But the fine tailings issues are still remaining because all the measures do not solve the liquid-solid separation problem in essential.

The primary separation vessel (PSV) is the major equipment for bitumen separation from oil sands slurry in extraction plant. The PSV produces a primary bitumen froth gathered in a launder from the top liquid layer of the vessel, a coarse tailings output from the bottom of the vessel, and a middlings stream that are removed from the mid-portion of the vessel. It has been found that production of the middlings varies with the fines and clay content of the originating oil sands. The middlings contain an admixture of bitumen traces, water and mineral material in suspension. The middlings are amenable to secondary separation of the bitumen by introducing air into the process flow in flotation cells. The introduced air causes the bitumen to be concentrated at the surface of the flotation cell. The flotation of the bitumen in preference to the solids components permits the air entrained bitumen to be extracted from the flotation cell. The air-entrained bitumen froth is also referred to as secondary froth and is a mixture of the bitumen and air that rises to the surface of the flotation cell. Typically, the secondary froth may be recycled to the PSV for reprocessing.

In order to improve liquid-solid separation efficiency cyclo-separator is proposed to replace the PSV. In cyclo-separators centrifugal action is used to separate the low specific gravity materials (bitumen and water) from the higher specific gravity materials (sand, clays etc). A multistage cyclo-separators may be involved in a counter-current backwash configuration. The cyclo-separator has a number of major disadvantages including: (1) the need to comminute large rocks and remove contaminants, such as wood and tramp metal from input streams to avoid damaging the cyclo-separator; (2) high rates of equipment wear and the concomitant need to use expensive abrasion resistant materials; (3) de-aeration of the recovered bitumen which causes problems for downstream stages of separation; and (4) cyclone failure or viscous plugging due to a black froth condition for high bitumen content ores.

Further treatment of the primary bitumen froth from the extraction plant requires removal of the mineral solids, the water and the air from the bitumen froth to concentrate the bitumen content. The current commercial froth treatment process includes three generations of solvent extraction technology. Originally, naphtha solvent-based dilution centrifuge process was developed and still used. In this process, two types of centrifuge systems have been deployed. One, called a solids-bowl centrifuge has been used to reduce the solids in froth substantially. To remove water and solids from the froth produced by a solids-bowl centrifuge; a secondary centrifuge employing a disk has been used. Disk centrifuges are principally de-watering devices, but they help to remove mineral as well. The bitumen product of the process has approximately 0.3-0.5% solids and 1-2% water by weight. This makes it unsuitable for pipelining and direct sale to traditional refineries.

Centrifuge units require an on-going expense in terms of both capital and operating costs. Maintenance costs are generally high with centrifuges used to remove water and solid minerals from the bitumen froth. The costs are dictated by the centrifuges themselves, which are mechanical devices having moving parts that rotate at high speeds and have substantial momentum. Consequently, by their very nature, centrifuges require a lot of maintenance and are subject to a great deal of wear and tear. Therefore, elimination of centrifuges from the froth treatment process would eliminate the maintenance costs associated with this form of froth treatment. Additional operating cost results from the power cost required to generate the high g-forces in large slurry volumes.

In order to eliminate centrifuge units from the froth treatment plant, some types of non-moving parts equipment were developed, including inclined plate separator and hydrocyclone, naphtha solvent is still used as diluent in the process. However, the bitumen quality is similar to the centrifuge process because of the nature of naphtha solvent extraction. The recovery of asphaltenes is attributed to the poor quality of the bitumen product because asphaltenes capture water and fines solids in their colloidal structures. As a result, the asphaltenes have to be removed in upgrader through delayed coking process before the final synthetic crude oil is sent to refineries.

In order to improve the quality of the dry bitumen product in froth treatment plant, paraffinic solvent process was developed more recently. This process could produce a pipelineable bitumen that is lower in asphaltenes and very low in water and solid contents, and can more easily be blended with other refinery feed stocks. This advantage may eliminate upgrader in the downstream, however, the disadvantage of the process is to generate asphaltene-containing tailings which needs to be stored separately for future recovery or backfill to the mining pit. There may be up to 10% of original bitumen to be disposed of as asphaltenes in the process, the ultimate bitumen recovery may be decreased to below 80% of original bitumen feed.

Recently, U.S. Patent 7,446,896 proposes a new concept of ‘tar sand excavation and bitumen extraction combine’ which is considered as the most efficient way to process oil sands. The concept proposes to excavate and process the oil sands ore as close to the excavation as possible. If this can be done using an underground mining technique, then the requirement to remove large tracts of overburden is eliminated. Further, if the tailings can be placed directly back in the ground, the tailings disposal problem is eliminated. The extraction process for removing the bitumen from the ore requires substantial energy. If a large portion of this energy can be utilized from the waste heat of the excavation process, then this results in less overall greenhouse gas emissions. In addition, if the ore is processed underground, methane liberated in the process can also be captured and not released as a greenhouse gas.

Currently the above concept is still an ideal situation because the backfill is impossible if the tailings issues are not solved. However, there is a great potential to achieve the goals by using innovative technologies like the present invention.

SUMMARY OF THE INVENTION

The present invention, in essential, is an integrated system and related apparatuses. The integrated system comprises a series of sub-systems, dependent or independent of each other. The integration of the sub-systems, as the integrated system, plays synergistic functions to produce de-asphalted bitumen from mined oil sands in a clean way by which tailings pond can be eliminated, zero waste liquid and solids are emitted into the environment. The system does not consume natural gas, and significantly reduces water consumption and greenhouse gas (GHG) emissions comparing with current oil sands processing technologies. The integrated system makes it possible for both ore preparation and extraction plants to be moveable easily so as to shorten the transport distance of massive solid streams between mining site and extraction plant.

A logical description of the integrated system is necessary to clearly explain the synergistic functions in brief.

The mined oil sands at mining site are sized and transported through pneumatic capsule pipeline to oil sands extraction plant. The oil sands are fed by dense phase pneumatic conveying from the oil sands receiving station into the oil sands surge tank. Then the oil sands are processed in a compact assembly for heating, conditioning, and primary separation to obtain bitumen froth, light phase middlings, dense phase middlings, and coarse tailings. The bitumen froth is sent to forth treatment plant after de-aeration. The light phase middlings are treated in light phase middlings flotation column to recover bitumen on the top, the underflow of the flotation column is recycled as warm water back to the conditioning assembly. The dense phase middlings are treated in dense phase middlings flotation column to recover the bitumen on the top, the underflow of the flotation column is combined with the fine tailings from froth treatment plant as the combined fine tailings stream to be treated in the fine tailings concentration assembly where the combined fine tailings stream is heated and concentrated through a thermal cycle of evaporation and condensation in a compact assembly for fine tailings concentration to obtain the concentrated fine tailings and steam condensate. The coarse tailings are de-watered in solids de-watering facilities, then, mixed with the concentrated fine tailings to prepare solid tailings for backfill at mining site through pneumatic capsule pipeline transportation. The bitumen froth fed into froth treatment plant is subject to a series of separation to obtain de-asphalted bitumen, asphaltenes, and fine tailings which are sent back to extraction plant for fine tailings concentration, as mentioned before. The asphaltenes separated from bitumen froth are used to prepare the asphaltene-based fuel, and the asphaltene-based fuel is used for fuelling the integrated system. The exhaust gas from the combustion of asphaltene fuel is treated in process streams and combined into the compressed air stream after treatment.

The innovative aspects of the present invention include using pneumatic capsule pipeline to convey both the oil sands ore and the solid tailings between mining site and extraction plant, using dense phase pneumatic conveying to transfer oil sands into the conditioning system, using a compact assembly to enhance oil sands heating, conditioning and primary separation, using a compact assembly to concentrate the combined fine tailings for eliminating fine tailings streams and producing steam condensate, using a process for solid tailings preparation, transportation, and backfill to mining site, using a process for separation of bitumen froth to obtain de-asphalted bitumen and asphaltenes, using a process for asphaltene-based fuel preparation, and using an arrangement of oil sands processing facilities to shorten the distance and reduce the transport loads between mining site, extraction plant, and froth treatment plant.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 describes the overall process flow diagram of the integrated system.

Figure 2 shows an arrangement of oil sands processing facilities.

Figure 3 describes an arrangement of pneumatic capsule pipeline for oil sands and solid tailings transportation with load/unload stations.

Figure 4 describes the dense phase pneumatic conveying feed system.

Figure 5 describes the oil sands surging, heating, conditioning, and primary separation assembly.

Figure 6 describes the fine tailings concentration assembly.

DETAILED DESCRIPTION OF THE INVENTION

The following discussion includes a detailed description of the integrated system and related apparatus for bitumen recovery from oil sands in accordance with the principles of the present disclosure, and illustrated in the accompanying figures. The preferred and alternate embodiments are also disclosed.

The overall schematic process flow diagram of the integrated system is shown in Fig. 1, and the brief description has been given in the summary above.

The integrated system comprises three sites, including mining site, extraction plant site, and froth treatment plant site. Logically, the mining site is located in the mining area close to the mining face, at mining site is the oil sands ore preparation station 101 and the solid tailing backfill station 102 as shown in Fig. 1. This type of arrangement intents to use pneumatic transport system to substitute for the trucking and belt conveying system that are currently employed for oil sands transportation from mining site to the oil sands ore preparation plant. This arrangement benefits the transportation of solid tailings from the extraction plant back to the mining site for backfill while avoiding sending empty capsules back to the mining site.

In regarding to the transport distance and the relationships of mining site, extraction plant, and froth treatment plant, a conceptual arrangement of the three plant locations is shown in Fig. 2. In contrast to the current oil sands processing facilities which transfer massive oil sands ore to central extraction and froth treatment plants by trucking over a long distance, the present arrangement considers a two-stage transfer of feed materials and discharge materials between the three oil sands processing facilities. As mentioned before, an ideal arrangement would be to locate both ore preparation plant and extraction plant at mining site and move with the mining face so as to minimize the oil sands transport distance, however, the current ore preparation and extraction facilities are designed for very large production capacity to meet the requirement of economic scale, it is impossible to move all the extraction plant with the mining progress, although the semi-mobile oil sands slurrying station has been tested recently. In order to optimize the transport distance and the plant capacity, the present invention proposes a conceptual arrangement of satellite distribution of multiple mining sites 203 surrounding an extraction plant 202, and satellite distribution of multiple extraction plants 202 surrounding a central froth treatment plant 201. The mining sites 203 are made fully mobile, and the extraction plants 202 are made semi-mobile, and the central froth treatment plant 201 is fixed permanently. As shown in Fig. 2, the capacity of the system is fixed based on the economic aspects, that is, the froth treatment plant 201 has a fixed output required, of course, the input of the plant should also be fixed. Here is the difference of the present invention and the current oil sands processing facilities in that the present invention divides the input of the froth treatment plant 201 into several smaller outputs from the surrounding extraction plants 202 which have smaller capacities, instead of a single extraction plant with the same capacity as that of the froth treatment plant. The output of extraction plant is bitumen froth, the amount of froth is less than 20 percent by weight of the oil sands feed into the extraction plant, which means more than 80 percent solids in oil sands feed can be sent back from the extraction plant to the mining site over a shortened distance if the extraction plant is not located close to the froth treatment plant, furthermore, if the extraction plant can become semi-mobile to move with the mining face progress or mining site change. The arrangement of multiple extraction plants 202 makes it possible for continuous production of the froth treatment plant 201 when one of the extraction plants 202 is relocated.

In a similar way, an extraction plant 202 can be surrounded by a set of mining sites 203 which comprise oil sands ore preparation stations and solid tailings backfill stations. This arrangement allows the mining capacity flexible at each mining site, and to be suitable for multi-site open-pit or underground mining. In the present invention, the distance between mining sites 203 and extraction plant 202 can be optimized through mining planning for the fully mobile stations 203 at mining site, or moving of the extraction plant 202 if necessary. The multi-mining sites also make the extraction plant 202 possible to operate continuously, when one of the mining sites 203 is relocated regularly. In addition to the reduction of transport distance, the small-ized the mining and extraction facilities make it possible for shop fabrication of equipment and assembly. The small-ization of capacity and equipment size specifically benefits the technology development of oil sands underground mining in the future, and encourages the investment of medium and small investors.

Pneumatic capsule pipeline 306 is used to transfer oil sands ore and solid tailings between mining site and extraction plant. Pneumatic capsule pipeline 306 is a pneumatic transport method by which the material is loaded in a number of capsules 305, the capsules 305 are mounted with wheels, several capsules are chained to form a train in a pipeline, and the train is conveyed pneumatically in the pipeline from one station to another. It is estimated that pneumatic capsule conveying is much cheaper than trucking and belt conveying, and flexible for changeable capacities. In the present invention, two direction pneumatic capsule pipelines 306 are linked between mining site 203 and extraction plant 202, and arranged with oil sands loading 301 and solid tailing unloading 304 stations at mining site 203, and oil sands unloading 302 and solid tailings loading 303 stations at extraction plant 202, as shown in Fig. 3. For example, the pipeline 306 passes both loading and unloading stations at the same location with the loading station is arranged above the pipeline and the unloading station is below the pipeline, thus the pipeline is kept straight, and the capsule is loaded right after it is unloaded, so as to keep the arrangement simple and compact, and the capsule 305 full all the time during it conveys between mining site 203 and extraction plant 202. For multi-mining sites 203 linked to one extraction plant 202, however, the loading 303 and unloading 302 stations in the extraction plant 202 are common for all pipelines 306 coming in and leaving from the stations, the difference of the stations 302 and 303 in extraction plant 202 from the stations 301 and 304 in the mining site 203 is the common stations have multiple pipelines going through them. The loading 303 and unloading 302 hoppers are made to allow for the operations of loading and unloading for multiple pipelines. On the other hand, the common stations can also be designed to be off-line of the two main pipelines which are linked with the pipelines coming in and leaving from the stations, then the loading and unloading operation can be done off-line, so as to avoid too big size of the common stations.

In a preferred embodiment for the arrangement of the integrated system with a capacity of 118,000 barrels of partially de-asphalted bitumen per stream day, the total oil sands feed rate is about 8,000 tonnes per hour for bitumen content of 11.1 percent by weight in oil sands feed. In a simplified case, the 8,000 tonnes per hour oil sands feed can be divided equally into four parts, each part has 2,000 tonnes per hour for a single extraction plant 202. Similarly, the 2,000 tonnes per hour oil sands feed to each extraction plant 202 can be further divided into four parts, each part has 500 tonnes per hour for a single mining site 203 in a mining face. As a result, the huge oil sands feed rate of 8,000 tonnes per hour is divided into multiple small mining capacities, and the distance of massive solid transport is also shortened and oil sands feed rate is divided into much smaller streams. For the extraction plant 202 with 2,000 tonnes per hour oil sands feed rate, the flow rate of the concentrated bitumen froth stream 205 is about 325 tonnes per hour, which can be sent to the central froth treatment plant 201 through a smaller pipeline. The central froth treatment plant 201 will produce about 765 tone per hour of partially de-asphalted bitumen 206, and feed back fine tailings and asphaltene fuel 204 for each extraction plant 203. The asphaltene rejection ratio can be controlled based on the quality of the de-asphalted bitumen and the energy demands of the integrated system based on the asphaltene fuel utilization.

In a preferred embodiment for pneumatic capsule pipeline system, a two direction pipeline system can be used for the transportation of both oil sands feed 207 and solid tailings 208. The distance between mining site 203 and extraction plant 202 can be limited within 5 kilo-meters, if the mining face exceeds the limit, then the extraction plant 202 may be moved forward to shorten the distance through further mining planning. The velocity of capsule train can be 10 m/s to 20 m/s, the loading and unloading time can be 6 seconds, the time for travelling of 5 kilo-meters at 15 m/s is about 333 seconds. If each train links three capsules 305, and each capsule loads 1.0 cubic meter of oil sands, that is about 1.5 tonnes of oil sands if a bulk density of 1.5 tonnes per cubic meter is assumed, therefore, the capacity of a train is 4.5 tonnes. For a 500 tonnes per hour oil sands feed rate, a total of 112 trains per hour is needed, and the time interval between two trains is about 32 seconds, and there are 10 to 11 trains running in the pipeline at the same time for the full long pipeline case, the distance between two trains is about 480 meters. If the length of each train is 5 meters, the pipeline filling ratio can be 1 percent when ten trains are running in the pipeline. In this case, the maximum length of pneumatic capsule pipeline is limited within 5 kilo-meters, the pipeline terminal facilities can be moved with the mining face, and there is no further increase of the facilities during the project lifetime, most of the facilities can be re-used, except for the replacement of damages. The maintenance and operating costs of pneumatic capsule pipeline are much less than those of trucking and belt conveying. For a two direction pipeline system running between four mining sites 203 and one extraction plant 202 may need a maximum length of 40 kilo-meters pneumatic pipeline to meet the requirement of a 2,000 tonnes per hour oil sands feed rate. However, in most case the real distance will shorter than 5 kilo-meters. If three mining sites 203 are considered, the total length can be reduced to 30 kilo-meters, and the capacity needs to be increased to 670 tonnes per hour. The change of capacity can be done by changing the pipeline diameter, the capsule flow velocity, or the pipeline filling ratio. The current commercial pipeline filling ratio is below 10 percent, therefore, there is a big potential to improve the utilization of the pipeline itself.

An alternative embodiment for multi-mining sites transportation of oil sands ore and solid tailings is to build-up a transit system similar to that for public transportation. The extraction plant is the central terminal to collect all coming oil sands feed and to dispatch all leaving solid tailings. There are several main pipelines extending radially to the farthest mining sites in different directions, while multiple branches of pipelines can be added along the main pipelines for the mining sites located between the extraction plant and the farthest sites. This type of arrangement can reduce the total length of pipelines, simplify the structure of loading and unloading stations at extraction plant, and increase the filling ratio of the main pipelines.

It is worthy noticing that the pneumatic capsule pipeline is specifically suitable for underground mining that needs a vertical lifting of oil sands from underground to the surface for extraction processing.

Another preferred embodiment using the same oil sands feed rate of 8,000 tonnes per hour, the 8,000 tonnes per hour oil sands feed can be divided equally into sixteen parts, each part has 500 tonnes per hour for a combination of a single extraction plant 202 and a single mining site 203. As a result, the distance between the combined extraction plant 202 and mining site 203 can be shortened so that there is no need for the long distance transport facilities between the two sites, instead, a dense phase pneumatic conveying system can be used for oil sands feed from the mining site 203 to the extraction plant 202, as shown in Fig. 4. In this case, several gathering and distributing stations may be added close to the extraction plants 202 to reduce the number of pipelines between extraction plants 202 and the central froth treatment plant 201. For example, the bitumen froth streams 205 from four extraction plants 202 can be combined together in a gathering station to from a stream at a flow rate of 325 tonnes per hour to feed to the central froth plant 201, in reverse, the central froth treatment plant 201 will send fine tailings and asphalten fuel 204 back to a distributing station at a relevant rate for the four extraction plants 202, then the distributing station will dispatch the streams for each extraction plant 202 accordingly. A compact extraction plant with high separation efficiency is needed in order to realize this kind of arrangements, the present invention proposes a solution to the compact extraction plant, as shown in Figures 1, 5, and 6, that will be described later.

The oil sands ore 207 from mining site 203 is unloaded in the oil sands unloading station 302 in extraction plant 202. The oil sand unloading station can be used as a surge bin to mitigate any change of oil sands feed rate, but the oil sands surge tank 501 will play the major surging function due to its pre-heating ability. The oil sands received at oil sands unloading station 302 are first transferred into the oil sands surge tank 501 through a dense phase pneumatic conveying system. Fig. 4 shows the dense phase pneumatic conveying feed system. The system comprises a horizontal pipe 401 and a vertical pipe loop 402, a loop of chained plates 403 is placed within the pipe loop 402. The chained plate loop 403 is used to help oil sands feed lift during pneumatic conveying. There are two air injection conduits in the system, the horizontal air jet 404 is to withdraw oil sands feed from the oil sands unloading hopper 302 into the horizontal pipe 401, then bringing the oil sands feed to the vertical pipe loop 402; the vertical air jet 405 is to booster the pressure of pneumatic conveying for lifting of oil sands feed. There may be more pressure boosters in the vertical pipe section of the pipe loop 402 for oil sands lifting. The chained plates 403 in the pipe loop 402 are used to form a stable plug flow of oil sands feed, and control the velocity of oil sands feed in the pipe loop 402. Warm water may be added into the oil sands unloading hopper 302 in order to reduce the friction between oil sands and the pipeline 401. For the oil sands feed into the surge tank 501, a part of the vertical pipe loop 402 is inserted into the surge tank 501 at the top, the pipe loop 402 inside the surge tank 501 is partially opened by removal of the bottom pipe wall 407 so that the oil sands feed can be discharged centrifugally and gravitationally into the surge tank 501. There may be warm water sprays toward the plates for cleaning in the surge tank 501. The objectives of using pneumatic conveying in extraction plant are to eliminate moving parts and reduce the space required for belt conveying, at the same time, make use of the compressed air system as a whole in the plant. The dense phase pneumatic conveying system has a higher efficiency and a lower cost as well.

In a preferred embodiment for the dense phase pneumatic conveying system with oil sands feed rate of 2,000 tonnes per hour, the velocity of the dense phase oil sands feed in the horizontal pipe 401 can be 1 m/s to 4 m/s, the preferred velocity is 2.5 m/s. The preferred pipe size of horizontal pipe 401 is 24 inches. The velocity of the dense phase materials in the vertical pipe loop 402 can be 1.5 m/s to 5 m/s, the preferred velocity is 3 m/s. The size of the vertical pipe loop 402 can be 10 inches to 30 inches in diameter, the preferred pipe size is 20 inches in diameter. The preferred chained-plate loop 403 can be a loop of plastic bowls chained by thick rubber bands piece by piece. In the vertical section of the pipe loop 402 for oil sands lifting, placing oil sands feed in bowls or plates can keep dense phase solids in a stable plug flow manner, while preventing oil sands from contact with the pipe wall, so as to reduce the friction loss and the wearing of the pipe, the bowl-type shape is useful for the oil sands discharge into the surge tank 501. The gap between two plates can be 0.4 meters to 1.2 meters, the preferred gap is 0.5 meters. The application of the chained-plate loop 403 in the pneumatic conveying system makes it possible for the pneumatic conveying system to easily control and reduce the operating cost due to the reduction of the air to solids ratio and pipe wearing rate.

The major separation of bitumen from oil sands happens in the assembly of oil sands surging, heating, conditioning, and separation. Fig. 5 shows the process flow diagram. The oil sands ore received in the extraction plant 202 are stored in a surge tank 501 for pre-heating and soaking by warm water 502, steam 503, and exhaust gas 504. Then the oil sands are fed into the heater 505 from the bottom of the surge tank 501 with the aid of gravity force and hot water jet flow 506. The pre-heated dense slurry enters the top side of the inclined heater 505 where steam 507 is injected from the top end and the side wall 508 of the heater. The downward end 509 of the heater 505 is linked to the conditioner 510 which is arranged vertically and connected with the heater 505 at the lower section of its cylindrical body. The temperature and density of the heated slurry are controlled at the outlet 509 of the heater 505 by further hot water injection 511 into the heater outlet 510. The heated slurry enters into the conditioner 510 tangentially along the sidewall to form a cyclone flow inside the conditioner 510, at the same time air 512 is added through jet flow from the bottom of the conditioner 510, and more air can be added from the sidewall of the conditioner 510 to aerate the heated slurry. The air jet flow 512 at the bottom of the conditioner 510 is also used to recycle large lumps 513 settled down in the pre-separator 514 in the downstream of the conditioner 510. The air to slurry volume ratio is controlled to maintain the slurry flow out of the top exit of the conditioner 510 without lump settling down in accordance with the geometric structure of the conditioner 510. The aerated hot slurry is further diluted by warm water injection 515 at the horizontal line 516 linking the conditioner 510 and the pre-separator 514, and air injection 518 at the pipe bent 519 toward the vertical line 520 to the pre-separator inlet. The further dilution and injection will result in a strong jet flow at the outlet 521 of the pre-separator feed line. With the jet flow large lumps would be shot more far away from the outlet 521 and more close to the bottom of the pre-separator 514. The jet flow will also force the light phase slurry moving up to the top of the pre-separator 514. As a result, the slurry in pre-separator 514 is separated roughly in light phase and dense phase suspension, and large lump settlings. There are three outlets in the pre-separator 514 at the top, the lower middle section, and the bottom, respectively, to deliver the light phase slurry 522, dense phase slurry 523, and the settled lumps 513 out of the pre-separator 514. As mentioned before, the settled lumps 513 are recycled through an inclined pipe 524 which is cross-linked the air injection conduit 525 at the bottom of the conditioner 510, any oversized lumps will be rejected by gravity force if the injection air 512 cannot bring the lump 513 into the conditioner 510 for recycle. The oversized lumps 513 will be collected in the oversize rejects bin 526 for disposal of, hot washing water 527 flows upward through the inclined pipe 524 to clean the oversize rejects 513, and prevents any small particulates from falling into the oversize rejects bin 526.

The pre-separated light phase 522 and dense phase 523 slurries are then introduced into the primary separation vessel (PSV) 528 at the light phase slurry inlet and the dense phase slurry inlet, respectively. The structure of the PSV is different from the conventional type. It contains two feed wells located in the center of the PSV at the upper middle section and lower middle section, respectively. The upper feed well 529 receives the light phase slurry 522 from the pre-separator 514, a set of inclined plates 530 forms a circle in the center to envelop the feed well and support the feed well in the center of the PSV, the circular structure with the feed well is then fixed onto the sidewall inside the PSV. The inclined plates will help with the separation of solids and water from bitumen attached with air bubbles in the slurry. Above the feed well is a gas release vent pipe 531 to deliver the entrained air directly into the vapour space of the PSV without disturbing the top liquid layer. There is a liquid distribution grid 532 between the top of the feed well 529 and the bottom of the gas vent pipe 531 for discharge of light phase slurry 522 from the top of the feed well 529 into the top liquid layer of the PSV. The lower feed well 533 receives the dense phase slurry 523 from the pre-separator 514. There are two circular structures 534 and 535 with inclined plates similar to the above mentioned one to envelop the lower feed well 533 at the top and the bottom section of the feed well and support the feed well in the center of the PSV 528, then the whole structure is fixed onto the sidewall of the PSV 528. Similarly, the inclined plates will help with the separation of solids and water from bitumen attached with air bubbles in the slurry, and will also help with the separation of coarse solids from fine particles in the slurry in the lower section of the PSV 528. The PSV has an inside launder 536 to collect bitumen froth from the overflow of the top liquid layer, and a cone bottom 537 to collect the settled coarse tailings 538. There may be one or more air injection nozzles 539 arranged in the cone section of the PSV to further clean the coarse tailings 538. The PSV has five discharge outlets at the top for gas release 540, at the launder collection outlet 541 for bitumen froth flowing to the de-aerator, at the upper middle section for light phase middlings 542 flowing to the light phase middlings flotation column or direct recycling to the conditioner, at the lower middle section for the dense phase middlings 543 flowing to the dense phase meddilings flotation column 601, and at the bottom for coarse tailings 538 flowing to the coarse tailings de-watering facilities, respectively. The froth from the PSV will be sent to froth treatment plant 201 after de-aeration. The light phase middlings 542 is used to control the level of the top liquid layer and the quality of the froth by controlling of flow rate and the density of related streams, a warm water stream could be used to adjust the parameters. The dense phase middlings 543 mainly containing fines in the slurry will be treated in a dense phase middlings flotation column 601 first to recover most bitumen in the stream, and then the fine tailings stream is mixed with the fine tailings stream from the froth treatment plant 201 to form a combined fine tailings stream which is concentrated in the fine tailings concentration assembly.

In a preferred embodiment for oil sands surging, heating, conditioning, and primary separation, oil sands are first pre-heated and soaked in the surge tank by steam, exhaust gas, and warm water. The liquid level in the surge tank is kept the same as the solid level in the tank, warm water can be circulated through overflow operation. The temperature of warm water can be 50 degree C to 75 degree C, the preferred warm water temperature is 65 degree C. The surge time of oil sands can be 20 min to 60 min, the preferred surge time is 30 min. For an extraction plant with capacity of 2,000 tonnes per hour oil sands feed rate, the volume required for 30 min surge time is about 800 cubic meters for water saturated oil sands. However, if multiple pneumatic conveying pipelines are used for oil sands feed into the surge tank, the surge time may be reduced to 10 min, resulting in a smaller size of the surge tank. The temperature of oil sands at the bottom of surge tank can be 10 degree C to 60 degree C, the preferred temperature is 45 degree C. It is expected that most of oil sands lumps can be soaked and become soft after 30 min surging in warm water.

When dense phase oil sands slurry is formed at the inlet of the heater after hot water injection into the oil sands stream, more steam and hot water are added to heat the oil sands slurry and control the slurry specific gravity (S.G.) required. The preferred hot water temperature is 90 degree C that is close to the hot water temperature of the condensate from the heat exchanger 603 in fine tailings concentration assembly, which will be described later in Fig. 6. The temperature of oil sands slurry at the outlet of the heater can be 60 degree C to 85 degree C, the preferred temperature range is 75 degree C to 85 degree C. The S.G. of oil sands slurry can be 1.4 to 1.6, the preferred S.G. is 1.5. The retention time of oil sands slurry in the heater can be 2 min to 10 min, the preferred retention time is 3 min, which guarantees the temperature of oil sands feed out of the heater high enough for bitumen to soak sufficiently. The size of the heater is about 100 cubic meters for heated oil sands slurry at 1.5 S.G. for a 2,000 tonnes per hour extraction plant. The heating steam is added through several nozzles located at the upper end and in the sidewall of the heater, the injection of low pressure steam also causes a strong agitation of the dense phase oil sands slurry in the heater, resulting in further size reducing of large lumps and agglomerating of bitumen drops, although the separation is limited. The arrangement of the heater in an inclined position helps the heated slurry flow gravitationally into the conditioner with the aid of static pressure of the surge tank and the hot water jet flow in the outlet of the heater, so as to eliminate slurry pumps which usually are costly trouble-makers in extraction plant, as well as directly links the surge tank, the heater, and the conditioner in a compact way.

The major function of oil sands conditioning is to separate bitumen from oil sand grains by transferring bitumen drops from surface of sand grains to surface of air bubbles in the present invention. The aeration is a fast step through thermal and mechanical forces to liberate bitumen drops from solids into free drops or aerated drops in the slurry. The oil sands slurry is further diluted using warm water to control the air-free S.G. within the range of 1.30 to 1.40 before the slurry fed into the conditioner. The air injection rate is determined by the volumetric ratio of air to slurry and the velocity of the mixture flowing upward the conditioner. The upward velocity can be 3.0 m/s to 6.0 m/s, the preferred velocity is 4.5 m/s. The conditioning time can be 2 seconds to 30 seconds, the preferred conditioning time is 5 seconds. In order to form an entrained slurry flow under given slurry flow rate, compressed air is injected from the bottom of the conditioner, the air jet flow is also used to withdraw the lumps settled in the pre-separator and recycled through the inclined lump transfer pipe. It is assumed that the largest lump size in the oil sands feed is 4 inches, the air jet flow can be designed to bring the lumps smaller than 1 inch to 3 inches back to the conditioner. For 5 seconds conditioning time at the velocity of 4.5 m/s, the size of the conditioner can be 20 meters to 30 meters in length with 20 inches to 30 inches in diameter for the aerated slurry of the 2,000 tonnes per hour oil sands feed rate. The temperature for oil sands slurry conditioning can be 55 degree C to 80 degree C, the preferred temperature is 65 degree C. In order to improve the gas distribution in the conditioner, several grids can be added in different elevations along the conditioner, and more air can be injected into the conditioner through its sidewall. This vertically arranged conditioner could benefit the slurry conditioning process because the retention time of particles would be divided depending on their particle size distribution. Small particles would go through faster than large particles because the relative velocity of light phase slurry along the upward passage is faster than that of dense solids which have bigger settling velocities. That means the conditioning process has a selective function to give more time for large particles while avoiding over conditioning for small particles.

Before the aerated slurry getting into the pre-separator, it is further diluted by warm water and air in order to enhance the pre-separation. The aerated oil sands slurry is injected into the middle section of the pre-separator, the jet flow results in the pre-separation after a certain retention time. The large particulates or lumps are shot to the bottom of the pre-separator and settled, the light phase slurry with more gas bubbles, bitumen drops, and fine particles are pushed upward to the top of the pre-separator, the dense phase slurry with less gas bubbles and bitumen drops, but more coarse sands, suspends in the middle section of the pre-separator. The settled lumps slide gravitationally along the inclined pipe to cross-link the air injection conduit at the bottom of the conditioner, most of the lumps can be entrained with the aid of air jet flow back to the conditioner for recycle, the oversized lumps which cannot be entrained by the air jet flow are then rejected into the oversize rejects bin through the inclined pipe. The retention time of fresh oil sands slurry in the pre-separator can be 0.5 min to 10 min, the preferred time is 1 min. The pre-separator can be less than 100 cubic meters in volume, and about 2 meters in diameter for 2,000 tonnes per hour oil sands feed rate if the volume of recycled lumps is not considered. However, one of the major functions of the pre-separation is to recycle the settled lumps back to the conditioner for further conditioning. The recycle is realized by control of the minimum particle size of lumps to be settled using an upward air jet flow at the bottom of the pre-separator. The minimum particle size of settled lumps can be 1 mm to 25 mm in diameter, the preferred minimum particle size is 2.5 mm in diameter. This particle size control will adjust the total amount of recycled slurry and the final effectiveness of conditioning. After pre-separation, the slurry is roughly separated into two streams: light phase slurry and dense phase slurry. The two streams of pre-separated oil sands slurry are introduced into the PSV.

The light phase slurry is directed to the upper feed well, the dense phase slurry is directed to the lower feed well. The slurry within the PSV is then separated further into four streams: the bitumen froth on the top of the liquid layer, which is collected by the internal launder and directed into the de-aerator, the light phase middlings which is withdrawn from the liquid layer underneath the first inclined plate shed, the dense phase middlings which is withdrawn from the liquid layer between the two inclined plate sheds for supporting of dense phase slurry feed well, the coarse tailings discharged from the bottom of the PSV is sent for the coarse tailings de-watering. The underflow of dense phase slurry feed well is further cleaned by air injection to enhance the recovery of bitumen and fines from the coarse tailings. The overall retention time of oil sands slurry in the PSV can be 1 min to 30 min, the preferred retention time is 6 min in air-free basis. The size of the PSV is about 800 cubic meters, the cross-sectional area required for gravitational settling is much smaller than that of conventional PSV because of the pre-separation, the cyclone-feed well and inclined plate installations.

One of the objectives that the present invention achieves is to eliminate tailings emission. The fine tailings concentration process is a key step to eliminate the emission of fine tailings into the fine tailings pond, as a result, the fine tailings pond is eliminated accordingly. Fig. 6 shows the process flow diagram of fine tailings concentration assembly. The fine tailings stream is formed from the combination of two fine tailings streams: one comes from the underflow 605 of the dense phase middlings flotation column 601, the other comes from the froth treatment plant 201. The combined fine tailings stream is first heated to a temperature required, then sent to a heat exchanger 603 which has both functions of evaporation and condensation. The combined fine tailings is treated through the heat exchanger 603 to form a concentrated fine tailings stream 607 by vaporizing partially water in the fine tailings in evaporation side of the heat exchanger, and a condensate stream 611 by condensing the vaporized water in the condensation side of the heat exchanger 603. The separation process utilizes a thermal cycle of water evaporation and steam condensation within the heat exchanger 603 to balance the energy required, while a compressor 604 outside the exchanger 603 is used to withdraw the steam generated in the evaporation side out of the exchanger, then the steam is compressed and sent back to the condensation side for steam condensation at a higher level of pressure and temperature. The total energy consumed in the separation process is the energy for steam compression, it is much smaller than the energy required for the evaporation or the condensation individually. Therefore, the process can be preceded at very low operating cost to realize the fine tailings concentration and steam condensate production under optimized process conditions. The concentrated fine tailings 607 are then mixed with de-watered coarse tailings to form solid tailings for backfill in the mining site.

Another feature in Fig. 6 is the fired furnace 602 which uses asphaltene fuel 609 to generate steam, and heat the process streams in extraction plant 202, and the exhaust gas 608 from the furnace is directed into the dense phase middlings flotation column 601 for heat recovery and cleaning. The vent gas 610 released from the top of the flotation column 601will also be sent to the oil sands surge tank 501 for further heat recovery and cleaning, as depicted in Fig. 1.

In a preferred embodiment for fine tailings concentration treatment, the temperature of the combined fine tailings stream after pre-heating can be 55 degree C to 92 degree C, the preferred range of temperature is 75 degree C to 87 degree C. This temperature combined with the pressure of the evaporation side of the heat exchanger is used to control the rate of vaporization of fine tailings in the exchanger. Accordingly the pressure of the evaporation side of the exchanger can be 50 kPa to 100 kPa absolute pressure, the preferred range of pressure is 70 kPa to 85 kPa absolute pressure. The pressure after compression can be 110 kPa to 190 kPa absolute pressure, the preferred range of pressure is 120 kPa to 150 kPa absolute pressure. The solid content of fine tailings fed into the exchanger can be adjusted by adding a part of coarse tailings, the preferred solid content in the fine tailings stream is 30 percent by weight, and the preferred solid content of the concentrated fine tailings is 60 percent by weight, which would make the fine tailing still pumpable and the volume of solid tailings prepared thereafter suitable for backfill. In case of immediate backfill operation, binder may be added into the concentrated fine tailings before the concentrated fine tailings are mixed with de-watered coarse tailings so as to get better dispersion of the binder. It is necessary to mix the concentrated fine tailings with coarse tailings and the fresh fine tailings before recycling it back to the exchanger.

An alternative embodiment for eliminating tailings streams in existing oil sands processing facilities is to de-water coarse tailings using de-watering means, combine two fine tailings from thickener underflow and froth treatment plant together, concentrate the combined fine tailings stream using the fine tailings concentration means mentioned above, and then mix the de-watered coarse tailings with the concentrated fine tailings to form solid tailings.

The type of heat exchanger is variable. The typical type is falling film evaporator which is widely used in the areas of process industry and wastewater treatment, however, the capacity is usually small. For the large scale applications like the fine tailings concentration process in oil sands processing, slurry spray technology can be combined into the evaporator to enhance water vaporization, so as to reduce the area required for heat exchange and mitigate surface fouling. Although the compact separation assembly has reduced the capacity to an extent to which a single fine tailings concentration assembly could handle the fine tailings feed, a multi-exchanger arrangement is recommended to make the process more reliable and flexible, and the size of each heat exchanger is small enough to be cleaned in a short period of time. For example, in the case of the oil sands feed rate of 2,000 tonnes per hour for an extraction plant, the feed rate of combined fine tailings into the exchanger is about 627 tonnes per hour with water content of 69.5 percent by weight. The water to be vaporized is 327 tonnes per hour, and the concentrated tailings are about 300 tonnes per hour. The total heat exchanged in the exchanger is about 770 GJ per hour through the thermal cycle of evaporation and condensation of water, the steam volumetric flow rate is about 73,000 cubic meters per hour under the operating conditions. Therefore, a bank of six exchangers with three compressors is necessary for the fine tailings concentration assembly to meet the requirements of separation and reliable operation. The total energy consumption for steam compression is about 35 GJ per hour, it is less than 5 percent of the exchanged energy, and moreover, there is 327 tonnes of steam condensate produced through this process for steam generation or hot water use in the system. That is, the fine tailing concentration assembly can be used as a water treatment unit to supply steam condensate for boilers to generate steam for the system. Fig. 6 depicts the concept with a fire furnace which further uses asphaltene fuel to eliminate the natural gas consumption in extraction plant. At the same time, the exhaust gas is treated through a series of process vessels to remove sour components from the gas. It is expected that the absorption of sour components in the slurry would improve the separation of solid particles from middlings in PSV and in flotation columns, as well as the precipitation of solids in fine tailings concentration process.

The solid tailings preparation is critical for solid tailings backfill. In the present invention, it is controlled by adjusting the water content in de-watered coarse tailings and the concentrated fine tailings to make the weight and volume of the solid tailings stream matching the oil sands feed weight and volume. Therefore, the water loss into the solid tailings is close to the amount of bitumen recovered from oil sands feed, this causes the total loss of water in the integrated system. In order to increase the strength and the yield stress of the backfilled solid tailings, some types of binders can be added into solid tailings, such as cement, starch, other crop-based binders, lime or clay in less than 1 percent by weight.

In a preferred embodiment for solid tailings preparation, the water content in de-watered coarse tailings can be 8 percent by weight to 20 percent by weight, the preferred water content is 12 percent by weight. The water content in concentrated fine tailings can be 15 percent by weight to 45 percent by weight, the preferred water content range is 35 percent by weight to 40 percent by weight. If vacuum belt filter is used for coarse tailings de-watering, the concentrated fine tailings can be pumped and added on the top of the filter cake of solid tailings, and the combined cake can be washed using cold fresh water to recover a part of the heat from the solid tailings, as well as reducing the temperature of the solid tailings below 45 degree C. The cooled filter cake is then removed from the belt into the solid tailings loading hopper 303 for transportation through pneumatic capsule pipeline 306. If a centrifuge decanter is used for coarse tailings de-watering, cold fresh washing water can be added into the decanter in the solid discharge side to reduce the temperature of the coarse tailings, then the de-watered coarse tailings can be discharged into an intermediate mixer to mix with the concentrated fine tailings from the fine tailings concentration assembly. The combined solid tailings are then sent into the solid tailings loading hopper 303 for transportation to mining site 203. The preferred temperature of the combined solid tailings is below 50 degree C.

In addition to the temperature control of solid tailings, the volume of the solid tailings needs to be controlled in order to meet the requirements of backfill. As mentioned before, the water content in solid tailings is critical for the volume control. It is assumed that the volume to be backfilled in the mining site is equal to the volume of mined oil sands from the same location. In practice the volume of dry sands is bigger than mined oil sands because of lack of bonding force, resulting in a larger void space formed in bulk dry sands after bitumen recovery, therefore, water may be added to resume the bonding force with the aid of binders. The addition of water and binder could meet both requirements of volume matching and yield stress matching. The water addition can be realized through adjusting the parameters during coarse tailing de-watering and fine tailings concentration, so as to obtain suitable water content within a required volume range. The addition of binder will not affect the volume much, but it is important to adjust the bonding force between solid particles. Therefore, the addition of binder should be done at mining site during backfilling operation. The cheap and convenient binder candidates may be cement, lime, or crop-based binders used in market, and the preferred dosage should be less than 1 percent by volume.

The bitumen froth fed into froth treatment plant is subject to a series of separation to obtain de-asphalted bitumen, asphaltenes, and fine tailings as shown in Fig. 1. The de-asphalted bitumen can be used as the refinery feedstock to be sent directly to downstream customers. The asphaltenes product is used to prepare for the emulsion fuel to meet the energy requirements of the integrated system. The fine tailings are sent back to relevant extraction plants for fine tailings concentration, as mentioned before.

In order to separate and recover asphaltenes from bitumen froth, two froth separation processes are combined in the present invention. In the first step the naphtha solvent extraction process is used to separate bitumen from bitumen froth, the dry bitumen is obtained after naphtha solvent recovery in the solvent recovery unit of the froth treatment plant 201, and the fine tailings is sent back to extraction plants 202 after tailings solvent recovery. In the second step, the paraffinic solvent extraction process is used to separate the dry bitumen into maltene and asphaltenes.

Traditionally, the dry bitumen product is sent to upgrader for production of synthetic crude oil through delayed coking and further hydrotreating. The delayed coke with about 90 percent carbon content by weight is not used currently because of its high sulphur content, and it becomes a solid waste to be piled in plant area. Some recent studies have been using coke gasification technologies to produce hydrogen through synthesis gas conversion, as well as co-generate steam and electricity. Different from the coke gasification method, the present invention proposes a process for liquid fuel production using asphaltenes generated from dry bitumen separation process. The liquid-state fuel has a high heating value and a small volume, it is easily to be transported to local industrial users for heating or steam generation, and the exhaust gas can be treated locally by conventional methods, or added into process streams for pre-treatment as proposed in the present invention. On the other hand, the current paraffinic solvent extraction process generates fine tailings with about 5 percent by weight to 12 percent by weight asphaltenes in the tailings, this type of TSRU tailings is not accepted by fine tailings pond for disposal of thickened fine tailings due to the presence of paraffinic solvent in it.

In order to obtain the highest profit from the bitumen recovery process, an integrated system combining bitumen extraction, froth treatment, and bitumen upgrading processes is preferred. In this case the asphaltenes rejection can be adjusted based on the energy requirements of the integrated system without using any natural gas in the system, the rejected asphaltenes and the residue from upgrading can be combined to produce emulsified residue fuel to fuel the whole system. On the other hand, the emulsified asphaltene fuel can be modified using other sources of heavy liquid fuels or solid fuels, such as delayed coke to adjust the energy balance of the system. As mentioned before, the asphaltene fuel can be used for heating and steam generation in extraction plant and froth treatment plant, as well as upgrader. If froth treatment plant is combined with upgrader, the energy efficiency would be improved significantly because the heat integration will benefits both plants, and the materials integration will eliminate the issues of diluent supply, fuel supply, hydrogen supply, general utilities supply, and emission control.

Although only several exemplary embodiments of this invention have been described in detail, it will be readily apparent to those skilled in the art that the integrated system, and the apparatus for implementing relevant processes, may be modified from the exact embodiments provided herein, without materially departing from the novel teachings and advantages provided by this invention, and may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Therefore, the disclosures presented herein are to be considered in all respects as illustrative and not restrictive. It will thus be seen that the objects set forth above, including those made apparent from the preceding description, are efficiently attained. Many other embodiments are also feasible to attain advantageous results utilizing the principles disclosed herein. Therefore, it will be understood that the foregoing description of representative embodiments of the invention have been presented only for purposes of illustration and for providing an understanding of the invention, and it is not intended to be exhaustive or restrictive, or to limit the invention only to the precise forms disclosed.

All of the features disclosed in this specification (including any accompanying claims, and the drawings) may be combined in any combination, except combinations where at least some of the features are mutually exclusive. Alternative features serving the same or similar purpose may replace each feature disclosed in this specification (including any accompanying claims, and the drawings), unless expressly stated otherwise. Thus, each feature disclosed is only one example of a generic series of equivalent or similar features. Further, while certain process steps are described for the purpose of enabling the reader to make and use certain processes shown, such suggestions shall not serve in any way to limit the claims to the exact variation disclosed, and it is to be understood that other variations, including various additives, may be utilized in the practice of the invention.

The intention is to cover all modifications, equivalents, and alternatives falling within the scope and spirit of the invention, as expressed herein above and in any appended claims. The scope of the invention, as described herein and as indicated by any appended claims, is thus intended to include variations from the embodiments provided which are nevertheless described by the broad meaning and range properly afforded to the language of the claims, as explained by and in light of the terms included herein, or the legal equivalents thereof.

WHAT IS CLAIMED IS

1. An integrated system for producing de-asphalted bitumen from oil sands, said system comprising:
   a) Mined oil sands ore preparation station at mining site;
   b) Oil sands ore transferring from mining site to extraction plant site through pneumatic capsule pipeline;
   c) Oil sands ore received from mining site transferring to surge tank through dense phase pneumatic conveying;
   d) An assembly for oil sands feed surging, heating, conditioning, and primary separation;
   e) Bitumen froth de-aeration;
   f) Light phase middlings flotation;
   g) An assembly for fine tailings concentration and steam condensate production;
   h) Coarse tailings de-watering;
   i) Solid tailings preparation and transferring from extraction plant site to mining site;
   j) Solid tailings backfill at mining site;
   k) A process for de-asphalted bitumen production from bitumen froth;
   l) A process for asphaltene fuel preparation;
   m) A process for treatment of exhaust gas generated from asphaltene fuel combustion.
2. The system as set forth in claim 1, wherein said mining site, further comprising:
   a) Surface mining site or open-pit mining site;
   b) Underground mining site.
3. The system as set forth in claim 1, wherein said oil sands ore preparation station, further comprising:
   a) A oil sands mining machine;
   b) An assembly of a crusher, a feed hopper, and a screen;
   c) A pneumatic capsule loading station;
   d) A mobile mechanism for movement of the said ore preparation station.
4. The system as set forth in claim 1, wherein said solid tailings backfill station at mining site, further comprising:

a) A pneumatic capsule unloading station;

b) Solid tailings stacking and transferring facilities for solid tailings backfill;

c) A mobile mechanism for movement of the said solid tailings backfill station;

5. The system as set forth in claim 1, wherein said pneumatic capsule pipeline, further comprising:

   a) A oil sands ore transferring pipeline, with or without branches of pipelines;

   b) A solid tailings transferring pipeline, with or without branches of pipelines;

   c) Air compression stations at both the mining site and the extraction plant site to supply pneumatic driving force and control the capsule movement;

   d) A number of capsules with wheels seating inside the pipelines for oil sands ore and solid tailings transfer between the mining site and the extraction plant site;

   e) Oil sands ore loading station at mining site and unloading station at extraction plant site;

   f) Solid tailings loading station at extraction plant site and unloading station at mining site;

   g) The stations for oil sands and solid tailings loading or unloading can be in-line or off-line of the said pneumatic capsule pipelines;

   h) A flexible pipe section in pneumatic capsule pipelines to separate the pipelines into fixed pipelines and mobile pipelines;

   i) A new flexible or straight pipe segment can be added regularly into the mobile pipelines to allow for the oil sands ore preparation station and the solid tailings stacking and backfill station to follow the further extension of the mining face.

6. The system as set forth in claims 1, 2, 3, 4, and 5, wherein said mining site, extraction plant, and froth treatment plant, further comprising:

   a) A fully mobile oil sands ore preparation station at mining site, which is moving with change of mining face regularly in a weekly basis;

   b) A semi-mobile extraction plant at extraction plant site, which is moving with change of mining site in a yearly basis;

   c) A fixed central froth treatment plant at froth treatment plant site, which is located in the same site permanently;

   d) Two pneumatic capsule pipelines linked between ore preparation station and extraction plant for oil sands ore feed to extraction plant and solid tailings backfill to mining site;

   e) Three conventional pipelines linked between extraction plant and froth treatment plant for bitumen froth feed from extraction plant to froth treatment plant, froth treatment fine tailings sending back from froth treatment plant to extraction plant, and asphaltene fuel prepared at froth treatment plant site sending to extraction plant;

f) More than one fully mobile oil sands ore preparation stations can be linked to an extraction plant which has one common oil sands unloading hopper and one common solid tailings loading hopper at the extraction plant site;

g) More than one semi-mobile extraction plant can be linked to a froth treatment plant;

h) An arrangement of oil sands ore preparation station and solid tailings backfill station, extraction plant, and froth treatment plant with a satellite distribution of more than one oil sands ore preparation stations and solid tailings backfill stations surrounding an extraction plant, and a satellite distribution of more than one extraction plants surrounding a central froth treatment plant.

7. The system as set forth in claim 1, wherein said dense phase pneumatic conveying, further comprising:

a) A horizontal pipeline for oil sands intake by air jet flow through the discharge outlet of the oil sands unloading hopper;

b) A vertical pipe loop next to the oil sands surge tank is connected with the said horizontal pipeline at the straight section close to the bottom bend;

c) A chained-plate loop inside the vertical pipe loop to help the oil sands lifting from below the ground level to the top level of the surge tank, the gap between two plates can be 0.4 meters to 1.2 meters, the preferred gap is 0.5 meters;

d) The chained plates can be other shapes with a certain side wall height, including bowl, bucket with conical bottom, or other vessels with opened top;

e) The chain used for chaining the plates can be made of metal, rubber, plastics, or other materials, the preferred chained-plate loop can be a loop of plastic bowls chained by thick rubber bands piece by piece;

f) A booster air injection conduit linked vertically toward to the straight vertical pipe from the bottom of the said vertical pipe loop;

g) A discharge pipe section of the vertical pipe loop is bended, and inserted into the surge tank for oil sands feed into the surge tank;

h) The said discharge pipe section of the vertical pipe loop inside the surge tank is opened from the highest point to the lowest point by removing a half of the pipe wall at the bottom, so that there is enough time for oil sands feed to be discharged by centrifugal force and gravitational force;

i) A solid plug flow is formed within the horizontal pipeline and the vertical pipe loop for dense phase pneumatic conveying. The velocity of the dense phase oil sands feed in the horizontal pipe can be 1 m/s to 4 m/s, the preferred velocity is 2.5 m/s. The velocity of the dense phase materials in the vertical pipe loop can be 1.5 m/s to 5 m/s, the preferred velocity is 3 m/s;

j) Water can be added into the oil sands feed to improve the plug flow formation and stability.

8. The assembly as set forth in claim 1, wherein said oil sands feed surging, heating, conditioning, and primary separation, said assembly comprising:

   a) A surge tank for oil sands feed surging, pre-heating, and exhaust gas treatment;

   b) A heater for oil sands feed heating and slurrying;

   c) A conditioner for oil sands slurry conditioning, specifically for aeration;

   d) A pre-separator for separation of conditioned oil sands slurry into light phase slurry, dense phase slurry, and settled lumps;

   e) A oversize rejects bin;

   f) A primary separation vessel (PSV) for separation of light phase slurry and dense phase slurry into bitumen froth, light phase middlings, dense phase middlings, and coarse tailings, as well as air release.

9. The apparatus as set forth in claims 1, 7, and 8, wherein said surge tank, further comprising:

   a) A closed vertical vessel with a cylindrical body and a conical bottom;

   b) Oil sands feed inlet and feed distribution parts inside the tank;

   c) A hot water injection nozzle located in the center of oil sands discharge outlet at the bottom of the tank;

   d) A nozzle at the bottom cone section for steam injection and distribution ring;

   e) A nozzle at the bottom cone section for exhaust gas injection and distribution ring;

   f) A set of warm water spray nozzles for cleaning of chained-plates passing through the open section of the pneumatic conveying pipe loop for oil sands feed into the surge tank;

g) A nozzle at the top of the tank for vent gas collection.

10. The apparatus as set forth in claim 8, wherein said heater, further comprising:
    a) A closed and inclined vessel with a cylindrical body and a conical bottom;
    b) The said oil sands discharge outlet from the bottom of the surge tank is linked to the sidewall of the heater tangentially at the upper end side of the heater;
    c) A steam injection nozzle is added at the upper end of the heater along the axial direction, but close to the bottom of the sidewall of the heater;
    d) Additional steam nozzles can be added along the sidewall of the heater;
    e) The lower end of the heater has a conical section, and the outlet of the conical section is linked to a horizontal pipe through which hot water is injected into the said conditioner.
11. The apparatus as set forth in claims 8 and 10, wherein said conditioner, further comprising:
    a) A closed vertical vessel with a cylindrical body and a conical bottom;
    b) A air injection nozzle at the center of the conical bottom;
    c) A heated slurry feed nozzle linked with the said horizontal pipe of the heater tangentially at the sidewall of the bottom section of the cylindrical body;
    d) Additional air injection nozzles can be added along the sidewall of the vessel.
12. The apparatus as set forth in claim 8, wherein said pre-separator, further comprising:
    a) A closed vertical vessel with a cylindrical body and a conical bottom;
    b) A U-shape slurry feed pipe linking the top of the conditioner and the top of the pre-separator with the pipe outlet inserted into the mid-section of the cylindrical body;
    c) A warm water injection nozzle is added horizontally to the inlet of the horizontal section of the U-shape pipe;
    d) A air injection nozzle is added vertically to the outlet of the horizontal section of the U-shape pipe linking to the pre-separator;
    e) A light phase slurry nozzle is added horizontally at the top of the pre-separator;
    f) A dense phase slurry nozzle is added horizontally at the lower section of the cylindrical body of the pre-separator;
    g) An inclined pipe is linked to the outlet of the conical bottom for discharge of settled lumps, the inclined pipe is cross-linked with the air injection pipe of the conditioner, and further downward to the top of the oversize rejects bin.
13. The apparatus as set forth in claim 8, wherein said primary separation vessel (PSV), further

comprising:

a) A closed vertical vessel with a cylindrical body and a conical bottom;

b) An internal launder for collection and discharge of bitumen froth overflow;

c) An internal cyclone-type feed well for light phase slurry feed into the PSV, the feed well is supported by a circular structure formed with a set of inclined plates, and a liquid distribution grid combined with a gas vent pipe is seated on the top of the feed well;

d) An internal cyclone-type feed well for dense phase slurry feed into the PSV, the feed well is supported by two circular structures formed with inclined plates;

e) An air injection and distribution ring is located underneath the underflow outlet of the dense phase slurry feed well;

f) A light phase middlings discharge nozzle is located in the liquid layer between the two cyclone-type feed wells;

g) A dense phase middlings discharge nozzle is located in the liquid layer between the two inclined plate circular structures of the dense phase slurry feed well;

h) A nozzle at the conical bottom for coarse tailings;

i) A nozzle at the top of the vessel for gas release.

14. The apparatus as set forth in claim 1, said bitumen froth de-aeration, further comprising a de-aerator, including inclined plate type, or shed-deck type.

15. The assembly as set forth in claim 1, said fine tailings concentration and steam condensate production, further comprising:

a) A dense phase middlings flotation column;

b) A fired furnace for steam generation and process heating, including fine tailings heating;

c) A heat exchanger for fine tailings evaporation and steam condensation;

d) A steam compressor for compression of steam from vaporized water in fine tailings.

16. The apparatus as set forth in claims 1 and 5, said coarse tailings de-watering, solid tailings preparation and solid tailings loading station, further comprising:

a) Mechanical coarse tailings de-watering facilities, including vacuum belt filter, or centrifuge decanter;

b) A mixer for mixing of de-watered coarse tailings and concentrated fine tailings;

c) A hopper for loading of solid tailings to capsules for pneumatic transfer to mining site.

17. A process for oil sands surging, heating, conditioning, and primary separation, using the

assembly as set forth in claims 1, 8, 9, 10, 11, 12, and 13, said surge tank, heater, conditioner, pre-separator, and primary separation vessel (PSV), to perform major bitumen separation from oil sands. The process further comprising:

a) Oil sands surging and pre-heating in the surge tank. Oil sands are heated and soaked by steam, exhaust gas, and warm water. The liquid level in the surge tank is kept a little higher than the solid level in the tank, warm water can be circulated through overflow operation. The temperature of warm water can be 50 degree C to 75 degree C, the preferred warm water temperature is 65 degree C. The surge time of oil sands can be 20 min to 60 min, preferred surge time is 30 min. The temperature of oil sands at the bottom of surge tank can be 10 degree C to 60 degree C, the preferred temperature is 45 degree C.

b) Oil sands slurrying and heating in the heater. The oil sands at the bottom of the surge tank is saturated with water, the dense phase oil sands slurry is formed at the inlet of the heater with hot water injection into the oil sands stream. Steam and hot water are used to heat the oil sands slurry and control the slurry specific gravity (S.G.) required. The preferred hot water temperature is 90 degree C. The temperature of oil sands slurry at the outlet of the heater can be 60 degree C to 85 degree C, preferred temperature is 75 degree C. The S.G. of oil sands slurry can be 1.4 to 1.6, the preferred S.G. is 1.5. The retention time of oil sands slurry in the heater can be 2 min to 10 min, the preferred retention time is 3 min.

c) Oil sands slurry conditioning in the conditioner. The conditioning of oil sands slurry is to aerate the heated oil sands slurry to enhance the transfer of bitumen drops on solid surface to air bubble surface. The oil sands slurry is further diluted using warm water to control the air-free S.G. within the range of 1.30 to 1.45. The air injection rate is determined by the volumetric ratio of air to slurry and the velocity of the mixture flowing upward in the conditioner. The upward velocity can be 3.0 m/s to 6.0 m/s, the preferred velocity is 4.5 m/s. The conditioning time can be 2 seconds to 30 seconds, the preferred conditioning time is 5 seconds. The temperature for oil sands slurry conditioning can be 55 degree C to 80 degree C, the preferred temperature is 65 degree C.

d) Oil sands slurry pre-separation in the pre-separator. The aerated oil sands slurry is injected into the mid-section of the pre-separator, the jet flow results in the pre-separation after a certain retention time. Before the aerated slurry getting into the pre-separator, it is further diluted by warm water and air in order to enhance the pre-separation. The large particulates or lumps are shot to the bottom of the pre-separator and settled, the light phase slurry with more gas bubbles, bitumen drops, fine particles is pressed upward to the top of the pre-separator, the dense phase slurry with less gas bubbles and bitumen drops, but more coarse sands suspends in the mid-section of the pre-separator. The settled lumps slide gravitationally along the inclined pipe to cross-link the air injection conduit at the bottom of the conditioner, most of the lumps can be entrained with the aid of air jet flow back to the conditioner for recycle, the oversized lumps which cannot be entrained by the air jet flow are then rejected into the oversize rejects bin through the inclined pipe. The retention time of fresh oil sands slurry can be 0.5 min to 10 min, the preferred time is 1 min. The minimum particle size of settled lumps in the pre-separation can be 1 mm to 25 mm in diameter, the preferred minimum particle size is 2.5 mm in diameter.

e) Oil sands slurry primary separation in the PSV. The two streams of pre-separated oil sands slurry are introduced into the PSV. The light phase slurry is directed to the upper feed well, the dense phase slurry is directed to the lower feed well. The slurry within the PSV is then separated further into four streams: the bitumen froth on the top of the liquid layer which is collected by the internal launder and directed into the de-aerator, the light phase middlings which is withdrawn from the liquid layer underneath the first inclined plate shed, the dense phase middlings which is withdrawn from the liquid layer between the two inclined plate sheds for supporting of dense phase slurry feed well, the coarse tailings discharged from the bottom of the PSV is sent for the coarse tailings de-watering. The overall retention time of oil sands slurry in the PSV can be 2 min to 30 min, the preferred retention time is 5 min in air-free basis. The released air is collected at the top of the PSV. The underflow of dense phase slurry feed well is further cleaned by air injection to enhance the recovery of bitumen and fines from the coarse tailings.

18. A process for fine tailings concentration and steam condensate production, using the assembly as set forth in claims 1 and 15, said dense phase middlings flotation column, fired furnace, heat exchanger, and compressor, the process further comprising:

a) Dense phase middlings flotation to recover bitumen entrained in the dense phase middlings, and treat the exhaust gas from the fired furnace;

b) The combination of fine tailings streams from the underflow of the dense phase middlings flotation column and the froth treatment fine tailings from froth treatment plant;

c) The asphaltene fuel from froth treatment plant is used in the fired furnace for heating and steam generation in the extraction plant;

d) The combined fine tailings pre-heating, concentration and producing steam condensate. The temperature of the pre-heated fine tailings can be 55 degree C to 90 degree C, the preferred temperature range is 75 degree C to 85 degree C. The pre-heated fine tailings is then concentrated in the fine tailing slurry side of the heat exchanger by partially vaporizing the water in fine tailings, the steam generated from the vaporized water is then compressed by the compressor to increase both the temperature and the pressure of the steam, the compressed steam is then sent back to the heat exchanger in the steam condensation side for exchanging heat with fine tailings and producing steam condensate. The pressure in the fine tailing slurry side of the heat exchanger can be 50 kPa to 110 kPa absolute pressure, the preferred pressure range is 70 kPa to 85 kPa absolute pressure. The pressure in the steam condensing side of the heat exchanger can be 110 kPa to 190 kPa absolute pressure, the preferred pressure is 120 kPa absolute pressure. The temperature of the compressed steam out of the compressor can be 100 degree C to 190 degree C, the preferred temperature is 150 degree C. The solid content of the concentrated fine tailings can be 40 percent by weight to 70 percent by weight, the preferred solid content is 60 percent by weight.

e) A binder can be added into the concentrated fine tailings before the fine tailings are mixed with the de-watered coarse tailings;

f) A coarse tailings stream can be added to the combined fine tailings before pre-heating so as to enhance the concentration of the fine tailings in the heat exchanger.

19. A process for solid tailings preparation in existing oil sands processing facilities, the process comprises:

a) Coarse tailings de-watering using de-watering means;

b) Fine tailings from thickener underflow mixing with fine tailings from froth treatment plant;

c) The combined fine tailings stream concentration using the concentration means mentioned in claim 18;

d) Solid tailings preparation by mixing the de-watered coarse tailings with the concentrated fine tailings.

20. A process for solid tailings preparation, using the apparatus as set forth in claims 1 and 16, to mix the de-watered coarse tailings and the concentrated fine tailings. The process further comprising:

a) The water content in the resulting solid tailings can be 10 percent by weight to 25 percent by weight, the preferred water content is 16 percent by weight;

b) Binders can be added into the solid tailings for stacking and backfill. Binders can be cement powder, powder of crop-based binders, clay powder, lime powder, and other types of dry or wet powder, or their paste;

c) The volume of the solid tailings prepared in extraction plant can be the same volume as that of the fresh oil sands ore sent to the extraction plant or 5 percent by volume smaller than the fresh oil sands ore.

21. The process as set forth in claim 1, said de-asphalted bitumen production, further comprising:

a) A bitumen froth separation unit which has an arrangement of a series of separators for bitumen separation from bitumen froth using naphtha solvent. The diluted bitumen product from the bitumen separation unit is then sent to the naphtha solvent recovery unit for naphtha solvent recovery, and the recovered naphtha solvent is recycled to the froth separation unit. The dry bitumen produced from the naphtha solvent recovery unit is sent to the maltene separation unit for separation of maltene and asphaltenes. The froth treatment fine tailing is sent back to the extraction plant after recovery of naphtha solvent.

b) A maltene separation unit which has an arrangement of a series of separators for maltene separation from the dry bitumen using paraffinic solvent. The diluted maltene product is then sent to the paraffinic solvent recovery unit for paraffinic solvent recovery, and the recovered paraffinic solvent is recycled to the maltene separation unit. The dry maltene is mixed with transport diluent to form a diluted maltene for transportation. The asphaltenes obtained by separation of maltene from dry bitumen is treated to recover paraffinic solvent first, then the asphaltenes is sent to asphaltene fuel preparation unit.

c) A process for production of de-asphalted bitumen and asphaltenes using a combined separation process with the first step using naphtha solvent extraction process and the second step using paraffinic solvent extraction process.

d) A process for partial de-asphalted bitumen production. The process is similar to the process for de-asphalted bitumen production, but the asphaltene rejection from dry bitumen can be within the range of 50 percent by weight to 95 percent by weight of asphalthenes in the dry bitumen, the preferred asphaltene rejection is 60 percent by weight.

e) A process for asphaltene emulsion fuel preparation. Asphaltenes, hot water, and emulsifiers are mixed and atomized to form an emulsion fuel. Delayed coke after grinding can be added into the emulsion fuel to improve the stability of the emulsion system.

22. The process as set forth in claim 1, said treatment of exhaust gas from asphaltene fuel combustion, further comprising:

a) The exhaust gas from the fired furnace is directed into the dense phase middlings flotation column;

b) The exhaust gas from the dense phase middlings flotation column is directed into the oil sands surge tank;

c) The vent gas from the oil sands surge tank is compressed, then directed into a purifier for removal of remaining sulphur-containing compounds, then recycled into compressed air system.

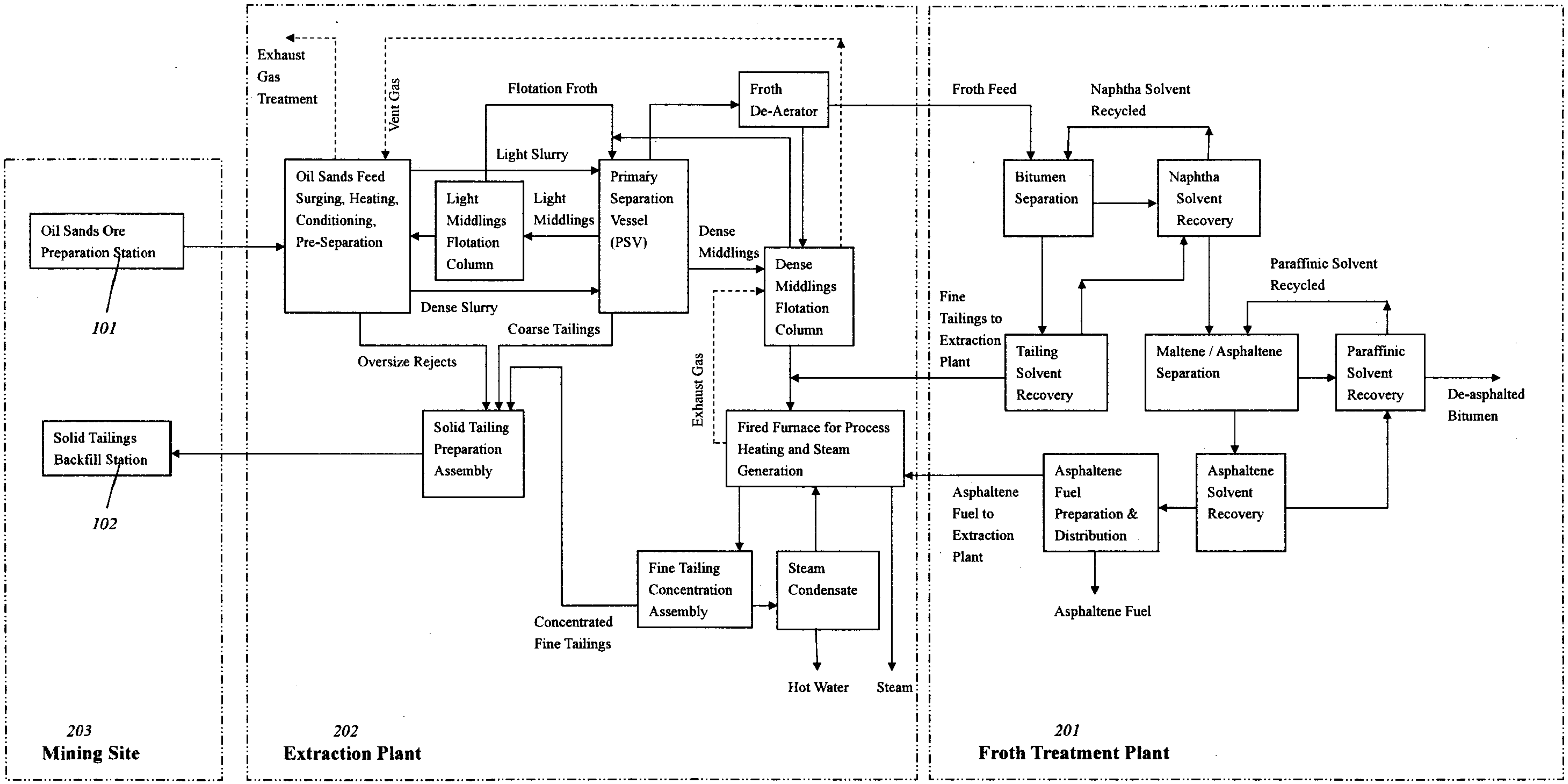


Fig. 1 Overall Process Flow Diagram of the Integrated System

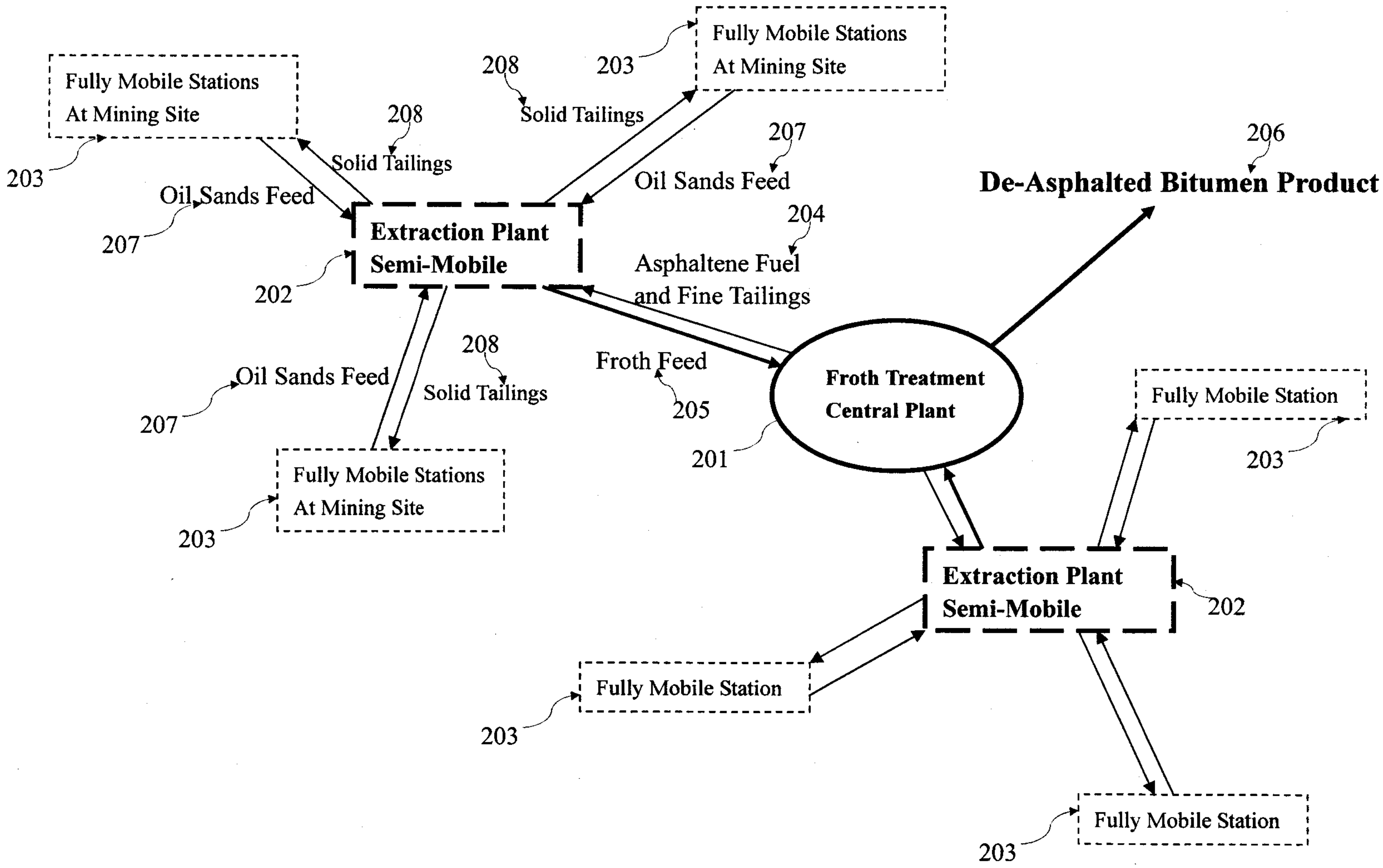


Fig. 2 Arrangement and Connection of Oil Sands Processing Facilities

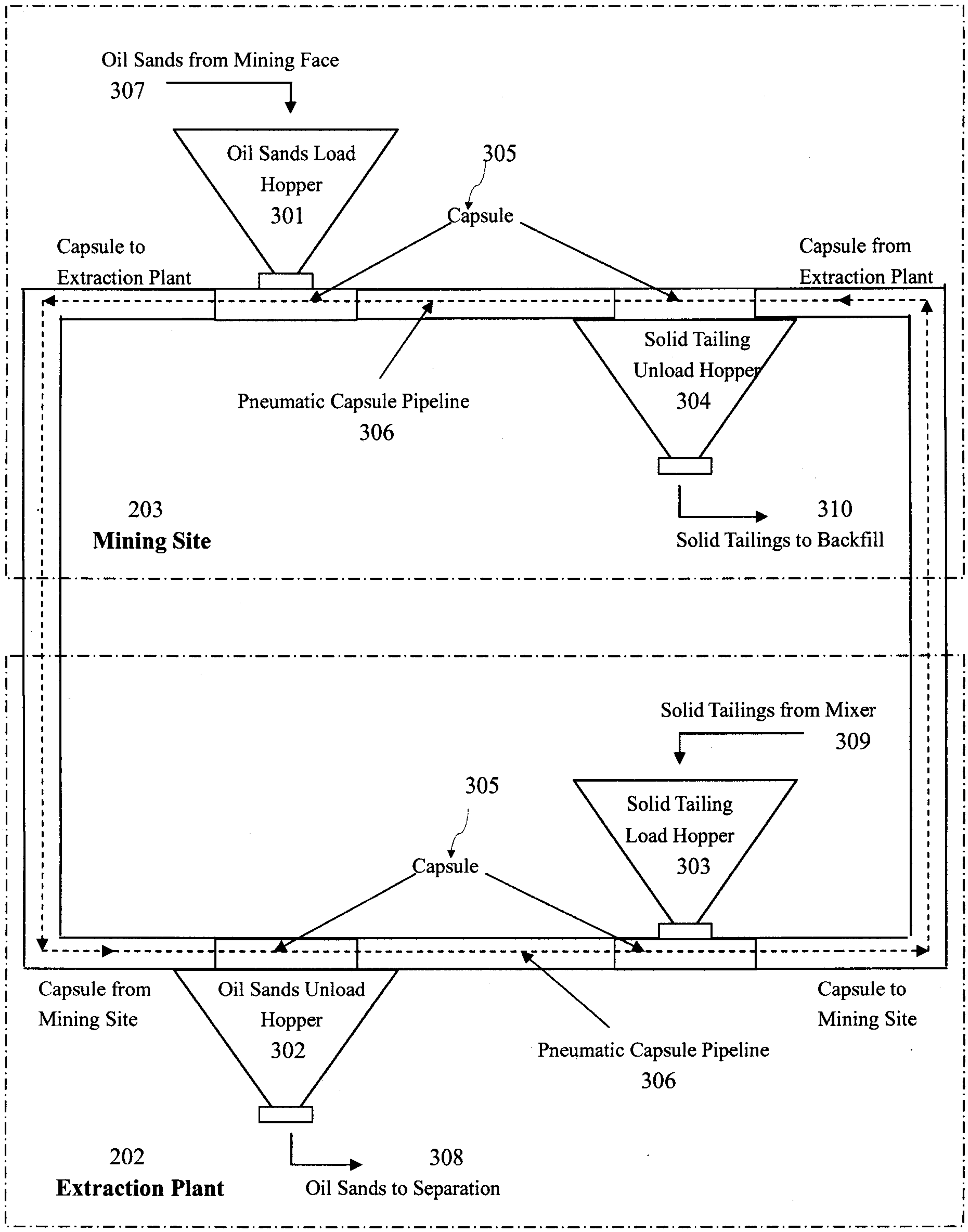


Fig. 3 Pneumatic Capsule Pipeline and Oil Sands and Solid Tailings Load/Unload

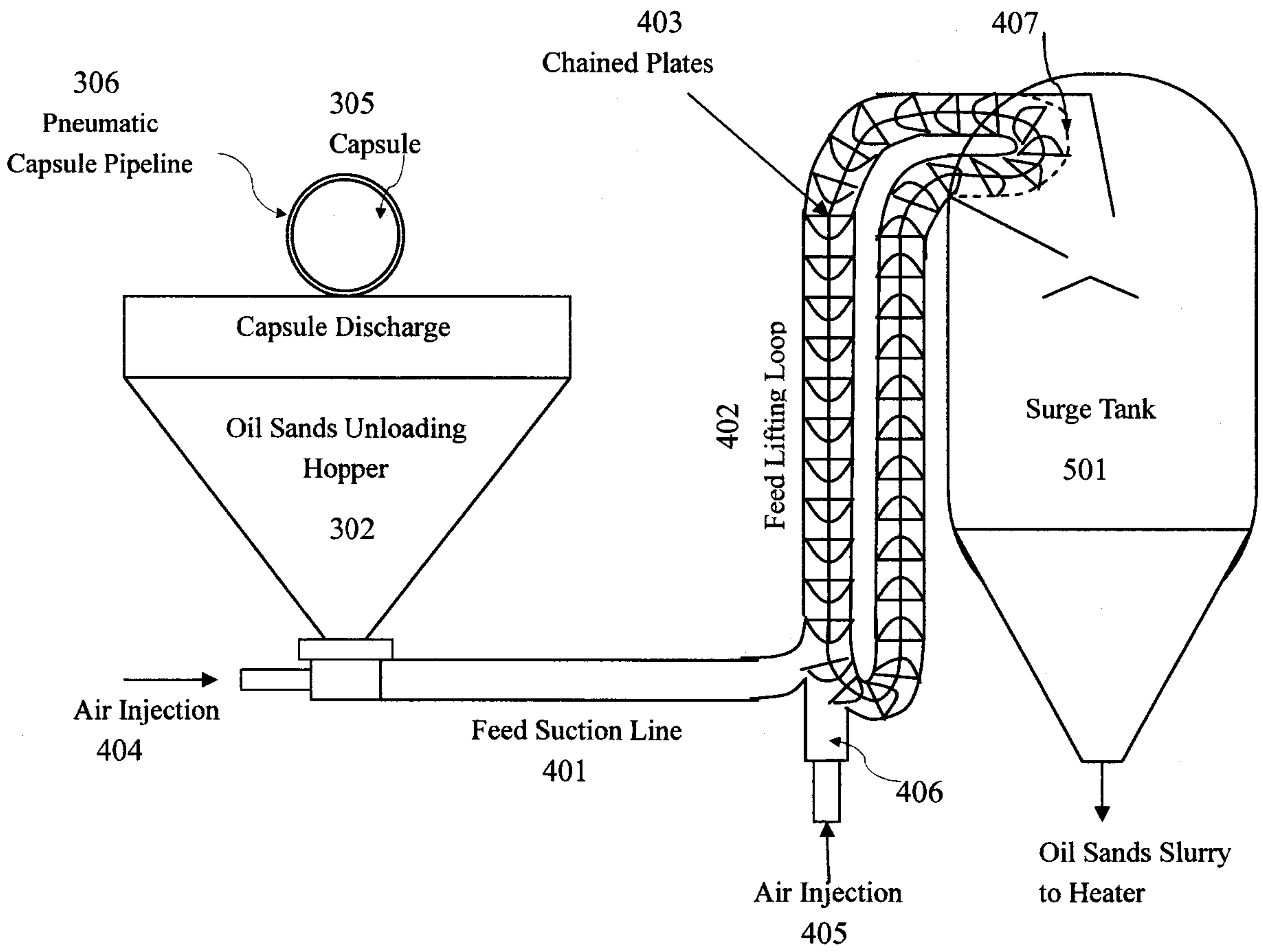


Fig. 4 Dense Phase Pneumatic Conveying for Oil Sands Feeding

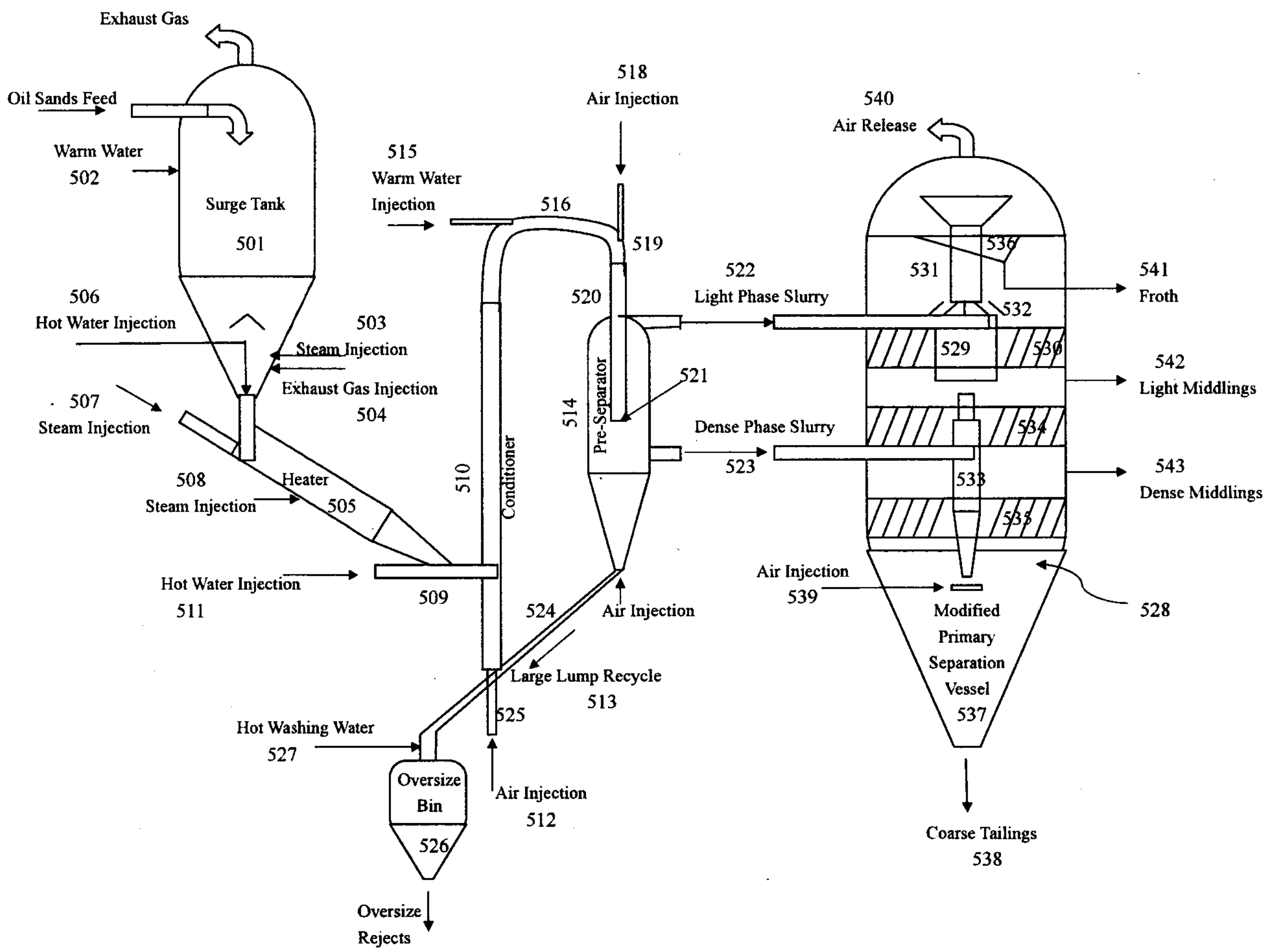


Fig. 5 Assembly of Oil Sands Surging, Heating, Conditioning, and Primary Separation

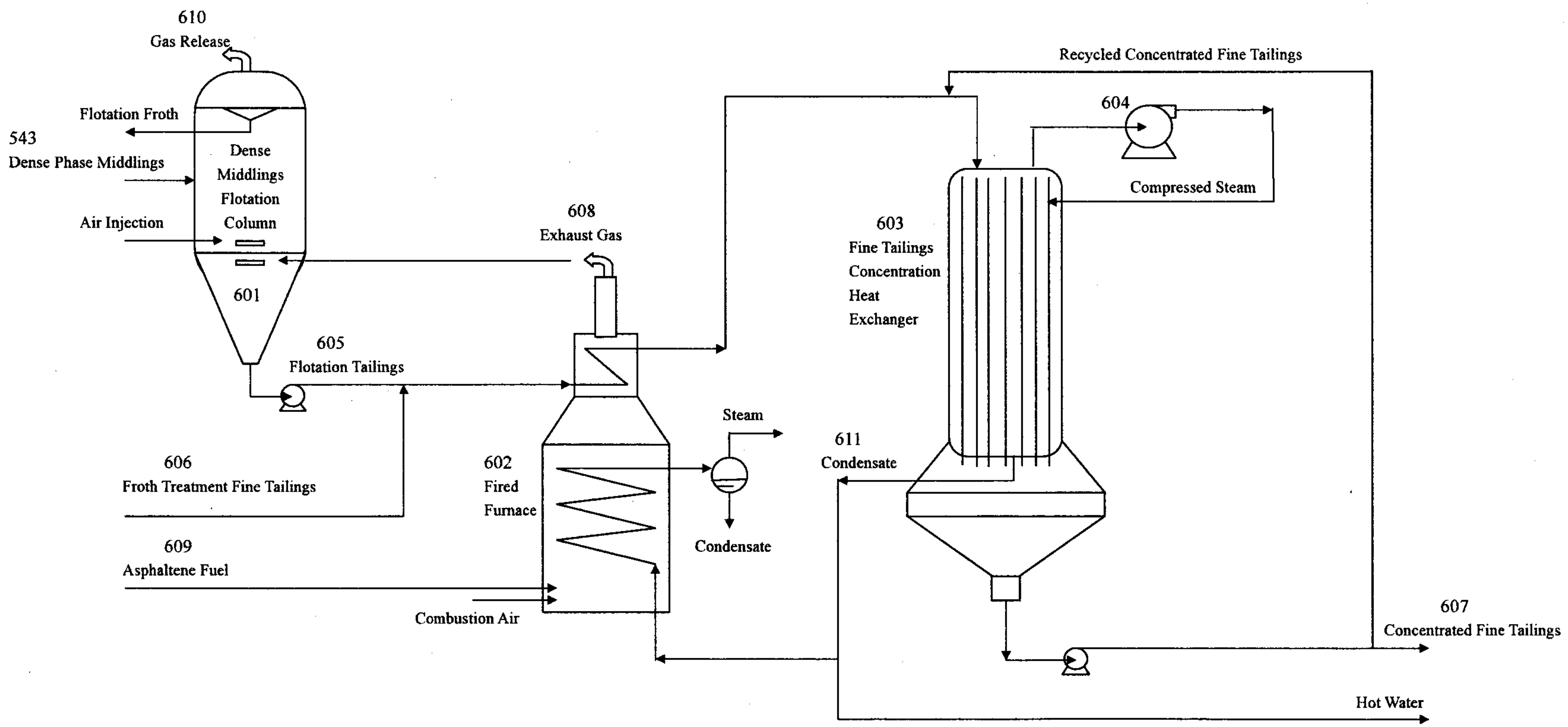
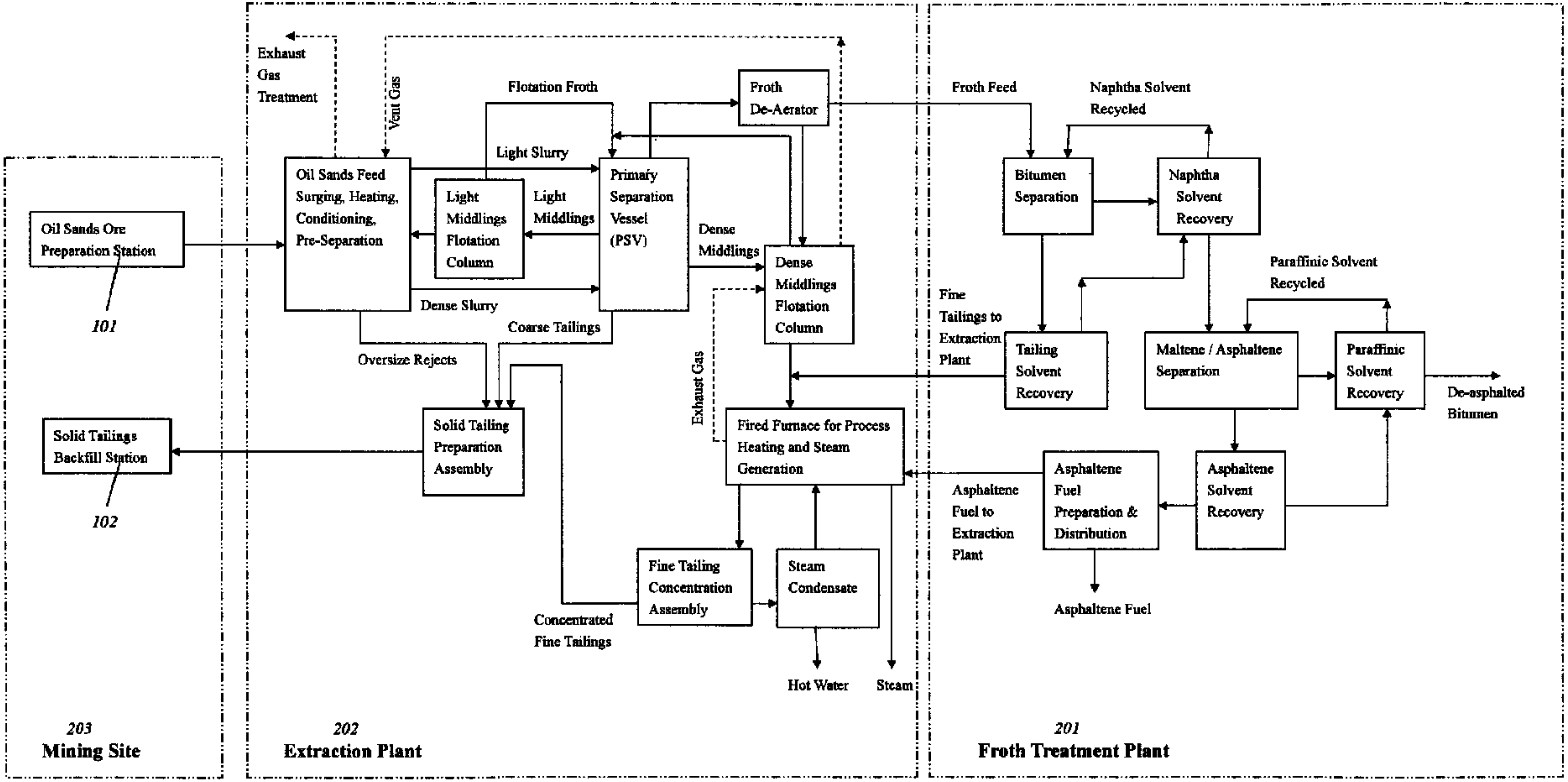


Fig. 6 Fine Tailings Concentration Assembly



Overall Process Flow Diagram of the Integrated System