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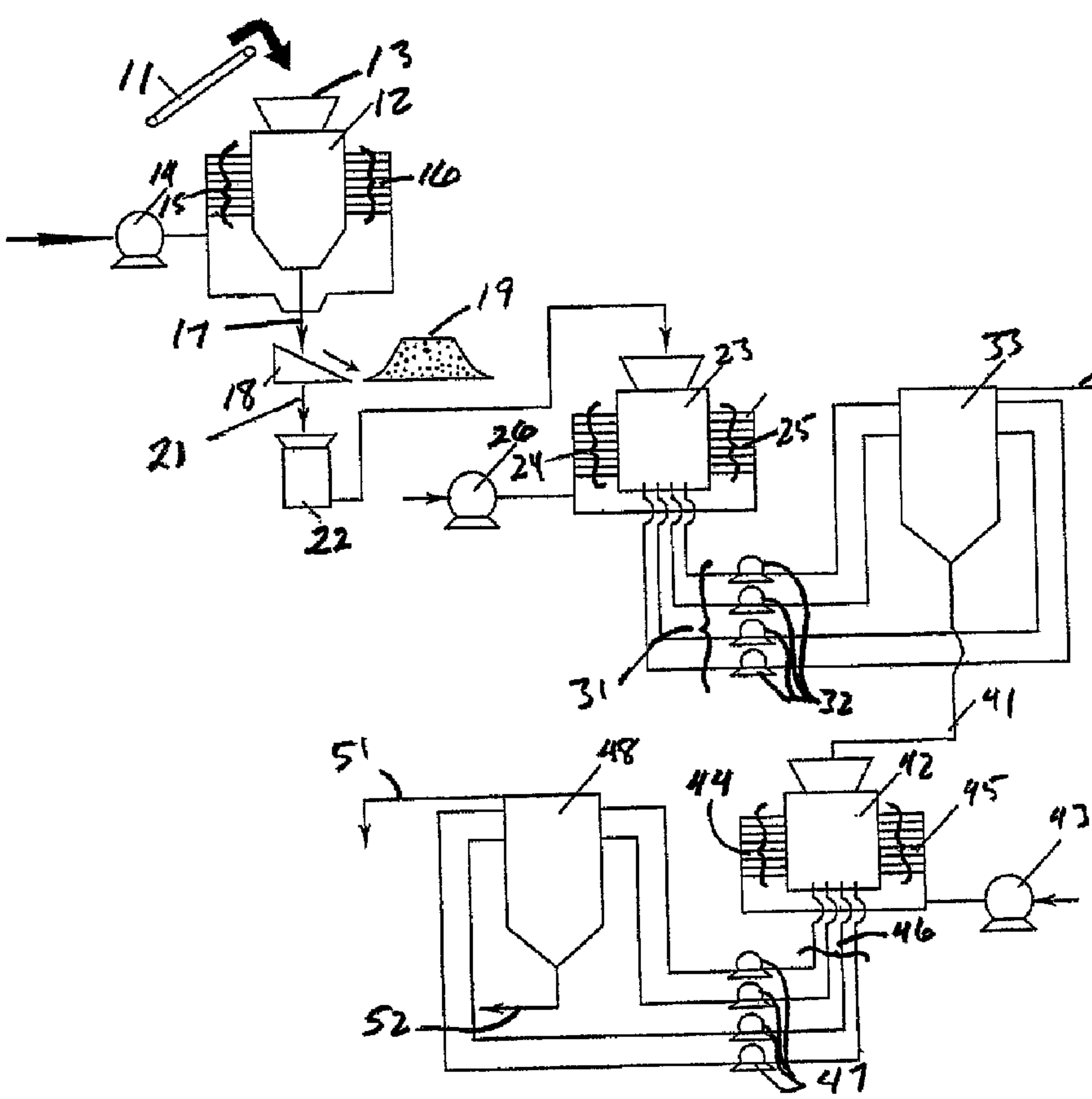
(54) **Titre :** EXTRACTION DU BITUME DES SABLES BITUMINEUX PAR CAVITATION
(54) **Title:** EXTRACTION OF BITUMEN FROM TAR SANDS WITH CAVITATION



(57) **Abrégé/Abstract:**
Bitumen is extracted from tar sands by pumping water through one or more cavitation nozzles into an aqueous suspension of the tar sands. Efficient release of the bitumen from the tar sands is achieved without the need for organic solvents, surfactants, or elevated temperatures.

ABSTRACT OF THE DISCLOSURE

Bitumen is extracted from tar sands by pumping water through one or more cavitation nozzles into an aqueous suspension of the tar sands. Efficient release of the bitumen from the tar sands is achieved without the need for organic solvents, surfactants, or elevated temperatures.

EXTRACTION OF BITUMEN FROM TAR SANDS WITH CAVITATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] This invention lies in the field of the recovery of bitumen from tar sands.

2. Description of the Prior Art

[0002] Tar sands, also known as oil sands, contain bitumen mixed with sand, clay, water, and certain metals such as iron, vanadium, nickel, and titanium. Tar sands occur extensively in Canada, and typical tar sands in Alberta, Canada, for example, contain approximately 10-12% bitumen by weight. The extraction of the bitumen from tar sands typically involves crushing and screening the as-mined material to remove oversized solids, mixing the screened solids with hot water and either organic solvents, surfactants, or both, in a cyclofeeder. The mixture formed in the cyclofeeder contains bitumen and solids in a combination of clusters, aggregates, and individual particles, plus water and air. Then, in a process referred to as "hydrotransport," this mixture is conditioned by being pumped through a pipeline of up to several kilometers in length, causing the bitumen to adhere to the air bubbles. The conditioned mixture then enters a primary separation vessel where the air bubbles and bitumen are recovered from the top of the vessel in the form of a froth.

[0003] The efficiency of this process depends in part on how well the tar sands, the water, and the solvents and surfactants, if any, are mixed in the cyclofeeder and on how dense a slurry is obtained. The degree of conditioning in the hydrotransport stage also affects the efficiency, since the contact of the released bitumen with the air bubbles and the ability of the resulting foam to float to the surface of the separation vessel depend on the residence time in the hydrotransport pipeline. In addition to efficiency concerns, the process suffers from a high operating cost due to a number of factors including the energy needed for heating the water, the energy consumed by the cyclofeeder in forming the slurry, and the energy consumed in pumping the slurry through the hydrotransport pipeline. The process also raises environmental concerns due to its use of organic solvents and surfactants.

[0004] Improvements have been achieved in the efficiency of bitumen extraction from tar sands by the use of acoustic energy. Early work using high-intensity sound waves on tar sands was reported by Bodine in United States Patents No. 3,123,546, issue date March 3, 1964, and No. 3,189,536, issue date June 15, 1965. A further study was reported by Hart et al., in United States Patent No. 4,054,506, issue date October 18, 1977. In Hart et al., the tar sands were suspended in an organic solvent in which the bitumen was soluble, and ultrasound was applied in combination with stirring. The Hart et al. process required three hours to extract 11% by weight of bitumen from approximately 100 grams of tar sands. Further descriptions of the use of ultrasound on tar sands is found in Jubenville, United States Patent No. 4,443,322, issue date April 17, 1984, and Davis et al., United States Patent No. 6,110,359. The limitations of ultrasound include the need for, and difficulty of achieving, proper tuning of the ultrasound transducer, and the sensitivity of the resulting vibrations to environmental conditions.

[0005] The use of cavitation is disclosed by Bacon Cochrane et al., United States Patent No. 6,074,549, issue date June 13, 2000, Bacon et al., United States Patent No. 6,527,960, issue date March 4, 2003, and Bozak et al., United States Patent No. 7,416,671, issue date August 26, 2009. The processes reported in these patents induce cavitation by pumping a slurry of the tar sands through a jet pump with a cavitating nozzle and use heated water with 50°C, 80°C, and 95°C variously cited as minimum temperatures.

SUMMARY OF THE INVENTION

[0006] It has now been discovered that bitumen can be extracted from tar sands by pumping water through one or more cavitation nozzles into an aqueous suspension of the tar sands without the addition of organic solvents and without using heated water. Unlike systems of the prior art that claim to induce cavitation by pumping the suspension itself through cavitating nozzles, the present invention pumps only water through the nozzles, and yet the resulting cavitation causes aggregates of the tar sands to be broken into smaller particles and bitumen to be released from the particles. The released bitumen can then be recovered by conventional means, including the use of separation vessels such as those used in bitumen extraction processes of the prior art. Hydrotransport is not required and its attendant costs can thus be eliminated, as well as the costs associated with heating the slurry or the water to be pumped through the cavitation nozzles. The inducement of cavitation by pumping water rather than a slurry of the tar sands through the cavitation nozzles offers the further advantage of reducing wear on the cavitation nozzles and extending their useful life.

[0006a] In accordance with one illustrative embodiment, there is provided a process for extracting bitumen from bitumen-bearing tar sands. The process includes combining the bitumen-bearing tar sands with water to form an aqueous suspension without adding an organic solvent. The process further includes inducing cavitation in the suspension by pumping liquid water at a temperature of 30°C or less into the suspension through cavitating jets immersed in the suspension, to cause the bitumen-bearing tar sands to disintegrate into granules while releasing liquid bitumen from the granules. The process further includes recovering the liquid bitumen from the suspension.

[0006b] In accordance with another illustrative embodiment, there is provided a system for extracting bitumen from bitumen-bearing tar sands. The system includes a cavitation vessel with an inlet for solid matter and an outlet for a solid-liquid suspension. The inlet and outlet define a direction of fluid flow through the cavitation vessel. The system further includes means for feeding water to the vessel through a plurality of cavitation jets directed transverse to the direction of flow to induce cavitation in liquid within the vessel. The system further includes a separatory vessel arranged to receive the solid-liquid suspension from the cavitation vessel and means within the separatory vessel for recovering non-water-miscible liquid organic matter from the suspension.

[0007] Illustrative embodiments of the invention can be efficiently practiced as a continuous-flow or discontinuous-flow process, and increased efficiency can be achieved by exposing the tar sands to cavitation in two or more stages with recovery of the released bitumen between successive cavitation stages. These and other features and advantages of illustrative embodiments will be apparent from the description that follows.

BRIEF DESCRIPTION OF THE FIGURES

[0008] FIG. **1** is a process flow diagram of a process scheme embodying an example of an implementation of an illustrative embodiment of the present invention.

[0009] FIG. **2** is a plot of test results investigating the effect of exposure time on bitumen extraction in accordance with an illustrative embodiment of the present invention.

[0010] FIG. 3 is a plot of test results investigating the effect of temperature on bitumen extraction in accordance with an illustrative embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS

[0011] Cavitating nozzles and jets are known in the art and available from commercial suppliers. One supplier is Dynaflow, Inc., of Jessup, Maryland, USA. Included among the products of this supplier that can be used in the practice of this invention are CAVIJET® Cavitating Liquid Jets and DYNASWIRL® Cavitating Swirling Jets. Descriptions of cavitating jets and their use are found in the following United States patents:

Johnson, Jr., et al., No. 4,262,757, issue date April 21, 1981
Johnson, Jr., et al., No. 4,389,071, issue date June 21, 1983
Johnson, Jr., et al., No. 4,474,251, issue date October 2, 1984
Conn et al., No. 4,508,577, issue date April 2, 1985
Johnson, Jr., et al., No. 4,681,264, issue date July 21, 1987
Conn et al., No. 4,716,849, issue date January 5, 1988
Chahine et al., No. 6,200,486, issue date March 13, 2001
Chahine et al., No. 6,221,260, issue date April 24, 2001

[0012] The term cavitation nozzles, is used herein to include both the nozzles themselves and the jets incorporating the nozzles. Preferred cavitation nozzles are those that produce cavitation while operating at a pressure of about 400kPa or greater, although depending on the other parameters of the system, the pressure needed for cavitation may be as high as 12mPa. More preferred nozzles are those producing cavitation within the range of about 400kPa to about 1,000kPa, most preferably from about 500kPa to about 800kPa, and a volumetric flow rate of at least about $0.001m^3/s$, preferably from about $0.001m^3/s$ to about $0.010m^3/s$, more preferably from about $0.003m^3/s$ to about $0.006m^3/s$. The flow rate through the nozzle is selected on the basis of the target production rate. For example, in a system with slurry flowing at a velocity of 3m/s through a pipe 0.75m in diameter into which cavitation is generated by 100 cavitating nozzles, the flow rate through each nozzle can be about $0.0132m^3/s$. In a presently contemplated implementation of the invention, the nozzle is designed to operate at a pressure of 551kPa and a flow rate of 0.003218m^3/s, producing flow with a Reynolds number of 3.089×10^5 and a Strouhal number of 0.34 at a resonating frequency of 612Hz and a cavitation number of 0.19. The optimal nozzle parameters will vary with the particulars of the application, and are readily determinable by routine experimentation.

[0013] As noted above, the bitumen-bearing tar sands in the practice of this invention are suspended in water preferably with no added surfactants and no added organic solvents, and more preferably no additives or other liquids of any kind other than those native to the tar sands, or entrained with the tar sands as the tar sands are extracted from their source or transported to the extraction plant. Exposure of the tar sands to cavitation is achieved with the cavitation jets submerged in the aqueous suspension and oriented to direct the cavitation through the suspension toward the tar sands and any aggregates present in the tar sands. In both continuous-flow and discontinuous-flow processes, the suspension flows as a fluidized stream past the cavitating nozzles which are aimed in a direction that is generally transverse to the direction of the gross movement of the fluidized stream. As used herein, the term "transverse" means crossing, although not necessarily at a right angle (90°). Crossing can also be at an oblique angle or an acute angle, although a right angle or an angle within 5 or 10 degrees of a right angle is preferred in most cases. Once the cavitation exposure stage is operating in a steady-state condition, the water in which the tar sands are suspended is supplied by the cavitating nozzles themselves, and the only inputs to the vessel in which the solids are exposed to cavitation are the solids, through an appropriate inlet port such as a hopper, and the water from the cavitating nozzles. The water from the nozzles thus replenishes the water that leaves the vessel through the outlet port with the conditioned suspension.

[0014] For optimal exposure in a flow-through vessel, cavitation nozzles are positioned on opposing sides of the vessel and directed toward the center of the vessel, thereby causing the suspension to be exposed to cavitation energy from more than one side. Thus, with vessels that are rectangular in cross section as well as those that are cylindrical, nozzles can be positioned on two opposing sides of the vessel or three or more nozzles can be distributed around the lateral walls or circumference of the vessel. Likewise, multiple nozzles can be spaced apart in the general direction of bulk flow of the solids through the vessel, *i.e.*, parallel to the axis of the vessel. Due to the nature of cavitation jets, the degree of cavitation and the energy generated by an individual jet will be maximal at a certain distance from the jet, and the jets, or the vessel walls on which the jets are mounted, can be positioned such that the greatest proportion of the tar sands will receive the maximal impact of the jets. This distance can be determined by routine experimentation. In most cases, however, with a flow-through vessel and cavitation jets on opposing walls (including opposing sites on a cylindrical wall), best results will generally be achieved with cavitation nozzles on opposing walls that are no more than 20cm apart, preferably no more than 15cm apart.

[0015] The proportion of bitumen and solids to water in the aqueous suspension is not critical and can vary widely. The optimal proportion for any given ore will vary with the composition of the ore, but will be readily determinable by routine experimentation. In most cases, best results will be obtained with a slurry in which the bitumen-bearing solids (tar sands, aggregates, etc.) constitute from about 0.5% to about 20%, preferably from about 1% to about 10%, by weight of the slurry. The upper limit on the solids concentration will depend on the residence time needed in the vessel for extraction of the bitumen, *i.e.*, the length of the pipe in embodiments where cavitation is performed in a pipe, and, also in the case of a pipe, the number of pumps used in forcing the slurry through the pipe.

[0016] Prior to entering the cavitation stage, and in particular prior to entering the first cavitation stage when multiple cavitation stages are present, the solids are preferably screened, and most preferably reduced in size by a preliminary size reduction, to optimize the effect of the cavitation. Screening can also be used to remove any solid materials that are not aggregated sand particles and that may be more resistant to being broken apart by the cavitation energy. These solid materials may be rocks, stones, or lumps of sand, bitumen and clay. The size cut-off for this screening of rocks and stones can vary, although in most cases a size cut-off that will produce useful results is about 10cm in diameter (the term "diameter" is used in this context to mean the average of the linear dimensions of the particles). The optimal size cut-off will vary with the vessel size, the pump size, and other flow-related parameters, and can be readily determined by routine experimentation. Separation of the rocks and stones from the tar sand aggregates can be enhanced by size reduction and can be achieved either prior to or simultaneous with the screening. Common equipment can be used for this purpose, such as a vibrating screen, or conventional grinding or impact mills. Size reduction screening can be performed either before any cavitation exposure or between successive cavitation exposure stages, or both.

[0017] As mentioned above, heating of either the solids, the water, or the slurry, is unnecessary in the practice of this invention, either prior to, during, or after the exposure of the slurry to cavitation. The temperature of the slurry during the cavitation exposure can thus be 30°C or less, or within the range of about 5°C to about 30°C, preferably 20°C or less, or within the range of about 5°C to about 20°C.

[0018] FIG. **1** is a process flow diagram to illustrate a continuous process scheme which is an example of an implementation of the present invention. In this process scheme, tar sand as mined is first crushed and screened, then transported by conveyor **11** to a cavitating vessel **12**, which is also referred to herein as a cavitation conditioning vessel (CCV), entering the vessel through a hopper **13**. A water pump **14** supplies water to the CCV **12** through a series of cavitating nozzles **15**, **16** on opposing surfaces of the vessel wall, creating an aqueous slurry of the tar sands inside the CCV and cavitation within the slurry. The cavitation produces a first intermediate slurry in which many of the solid aggregates have been broken up into smaller particles. This first intermediate slurry **17** is passed through a screen **18** that rejects rocks and other oversized solids **19** from the slurry. The residual slurry **21** is then conveyed by a pump **22** to a second cavitation conditioning vessel (CCV) **23** which also contains cavitating nozzles **24**, **25** supplied with water from a pump **26**. The conditioned slurry emerging from this second CCV **23** is fed through a series of pipes **31** and pumps **32** to a first separation vessel **33** in which the froth **34** containing the bitumen that has been released from the solids in the CCVs **12**, **23** is allowed to float to the top and is skimmed or decanted off. The remaining slurry **41** is directed to a third cavitation conditioning vessel (CCV) **42** where the slurry is likewise subjected to cavitation by a water pump **43** pumping water through arrays of cavitating nozzles **44**, **45**. The conditioned slurry emerging from this third CCV **42** is fed through a series of pipes **46** and pumps **47** to a second separation vessel **48** in which the froth **51** containing the bitumen that has been released from the solids in the third CCV **42** is allowed to float to the top and is skimmed or decanted off. The remaining slurry **52** consists essentially of clean sand and water.

[0019] The CCVs represented in FIG. **1** are rectangular tanks with vertical axes (centerlines), and the bulk flow direction through each tank is in the axial direction downward. Alternatively, the tanks can be replaced with horizontal pipes whose walls are lined with cavitation nozzles both encircling each pipe and extending along the length of each pipe. The pipe diameters will be subject to the same considerations, set forth above, as the widths of the vertical tanks.

EXAMPLES

[0020] A bench-scale experimental apparatus was constructed as a rectangular box with an aluminum frame. Aluminum mesh of 200 mesh size (200 wires per linear inch) formed three sides of the box while a fourth side was transparent acrylic to allow observation, a fifth side was a solid wall, and a movable plate formed the sixth side opposite the solid wall. A cavitating nozzle extended through the center of the fixed solid wall, and the movable plate served to control the distance between the nozzle and an aggregated sample of bitumen-bearing tar sands placed in the box. The volumetric capacity of the box was approximately 4,600cm^3. The cavitating nozzle had a pipe diameter of 33mm, a length of 610mm, and an orifice area of 2.01cm^2. The box was placed inside a larger vessel to collect water and cleaned sand that passed through the mesh sides of the box during the experiments. For the experiments, water was supplied to the nozzle by a centrifugal pump operating at 15hp and 3450rpm. In certain experiments a non-cavitating nozzle was used in place of the cavitating nozzle for comparison. The non-cavitating nozzle had dimensions identical to the cavitating nozzle, except for an orifice area of 1.94cm^2.

[0021] For each experiment, a sample weighing 100g was placed in the box. Eight samples were analyzed for bitumen content and sand contents, and the results were as shown in Table I.

TABLE I

Sample Contents (Prior to Treatment)

	Bitumen, g	Sand, g
	16.45	83.43
	15.74	83.85
	14.63	84.91
	13.11	86.83
	12.44	87.49
	15.06	84.89
	11.97	87.95
	14.55	85.47
Averages:	14.24	85.60

[0022] Additional samples, each weighing 100g, were placed in the apparatus and impinged by water jets at 12°C through cavitating or non-cavitating nozzles for three minutes in a transient pump regime – 50 seconds with flow rate 27.5 US gpm, then 50 seconds with flow rate 36.3 US gpm, and then 40 seconds with flow rate 43.1 US gpm, with 40-second transition times between regimes. These regimes were followed with a flow rate of 51.3 US gpm for ten minutes. Water and cleaned sand passed through the mesh plates, while the extracted bitumen and remnants of the tar sand were collected at the bottom of the sample box. After each experiment, the box was disassembled and cleaned, and the amounts of recovered bitumen and clean sand were measured for each sample. The results are listed in Table II.

TABLE II

Experimental Results Comparing Cavitating vs. Non-Cavitating Nozzles.

Sample	Cavitating Nozzle		Non-Cavitating Nozzle	
	Bitumen, g	Clean Sand, g	Bitumen, g	Clean Sand, g
1	12.56	13.08	12.74	7.53
2	13.76	18.64	14.51	3.69
3	12.39	13.57	13.78	3.61
4	17.10	16.53	13.42	6.04
5	15.79	14.17	12.01	7.05
6	14.36	13.60	13.17	6.20

[0023] The results in Table II indicate that the cavitating jet is more effective on the average in separating bitumen from clean sand than the non-cavitating jet.

[0024] The effect of residence time was investigated by performing experiments on six samples, each 100g in weight, with the cavitating jet under the same conditions as those used in the experiment above, but stopping the treatments at intervals of 1 minute, 2.5 minutes, 5 minutes, 7.5 minutes, and 10 minutes, and removing and weighing the cleaned sand at each interval. The cumulative amounts are plotted in FIG. **2** where each time interval is represented by a different symbol (diamonds, circles, triangles, small squares, and plus signs), the average for each time interval is indicated by a large square, and a curve is fitted to the average values. The plot shows that once steady state was achieved at three minutes, the rate of removal of bitumen from the sand was approximately constant.

[0025] The effect of water temperature was investigated by performing experiments on six samples for each temperature, using temperatures of 5.1°C, 12°C, 25°C, 35°C, 45°C, and 55°C. The sample size and operating conditions were otherwise the same as in the experiments described above, and the exposure time in each case was ten minutes at steady state. The amounts of cleaned sand were weighed in each case and are plotted in FIG. **3** where each temperature is represented by a different symbol (diamonds, squares, small triangles, ×'s, asterisks, and circles), the average for each temperature is indicated by a large triangle, and the average values are connected by a line. The plot shows that the extraction rate at temperatures of approximately 20°C and above does not increase with further increases in temperature.

[0026] An experiment was also performed to investigate the effect of varying the distance between the cavitating jet and the sample. To perform this experiment, a box with no sample but with a flat 24-gauge aluminum plate attached to the movable plate was used, and water was pumped through the cavitating jet with the movable plate at various distances from the jet. Photographs showed that the cavitation produced pitting in the plate, that the highest degree of pitting occurred when the distance was 0.06m, and that no pitting occurred at a distance of 0.09m.

[0027] In the claims appended hereto, the terms "a" and "an" are intended to mean "one or more." The terms "comprise" and variations thereof such as "comprises" and "comprising," when preceding the recitation of a step or an element, are intended to mean that the addition of further steps or elements is optional and not excluded. All patents, patent applications, and other published reference materials cited in this specification are hereby incorporated herein by reference in their entirety. Any discrepancy between any reference material cited herein or any prior art in general and an explicit teaching of this specification is intended to be resolved in favor of the teaching in this specification. This includes any discrepancy between an art-understood definition of a word or phrase and a definition explicitly provided in this specification of the same word or phrase.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A process for extracting bitumen from bitumen-bearing tar sands, said process comprising:

(a) combining said bitumen-bearing tar sands with water to form an aqueous suspension without adding an organic solvent;

(b) inducing cavitation in said suspension by pumping liquid water at a temperature of 30°C or less into said suspension through cavitating jets immersed in said suspension, to cause said bitumen-bearing tar sands to disintegrate into granules while releasing liquid bitumen from said granules; and

(c) recovering said liquid bitumen from said suspension.

2. The process of claim **1** wherein steps (a), (b), and (c) are performed without adding surface-active substances to said bitumen-bearing tar sands, said water, or said aqueous suspension.

3. The process of claim **1** wherein steps (a), (b), and (c) are performed as a continuous-flow process.

4. The process of claim **1** wherein steps (a), (b), and (c) are performed as a discontinuous-flow process.

5. The process of claim **1** in which said suspension remaining after step (c) is defined as a residual suspension, said process further comprising:

(d) inducing cavitation in said residual suspension by pumping liquid water at a temperature of 30°C or less into said residual suspension through cavitating jets immersed in said residual suspension to cause residual bitumen-bearing tar sands therein to disintegrate into granules while releasing liquid bitumen from said granules; and

(e) recovering liquid bitumen released in said (d).

6. The process of claim **3** or claim **4** comprising a plurality of stages including an initial stage and a final stage, each stage comprising steps (b) and (c), and wherein said suspension remaining after step (c) of each stage other than said final stage is used as said suspension of step (b) of a succeeding stage.

7. The process of claim **3** or claim **4** wherein step (b) is performed in first and second stages, each stage comprising pumping liquid water into said suspension through cavitating jets, and said process further comprises screening said suspension between said first and second stages to remove therefrom solid matter greater than 10cm in diameter.

8. The process of claim **1** wherein said temperature is 20°C or less.

9. The process of claim **5** wherein said temperatures of steps (b) and (d) are 20°C or less.

10. A system for extracting bitumen from bitumen-bearing tar sands, said system comprising:

a cavitation vessel with an inlet for solid matter, an outlet for a solid-liquid suspension, said inlet and outlet defining a direction of fluid flow through said cavitation vessel;

means for feeding water to said vessel through a plurality of cavitation jets directed transverse to said direction of flow to induce cavitation in liquid within said vessel; and

a separatory vessel arranged to receive said solid-liquid suspension from said cavitation vessel and means within said separatory vessel for recovering non-water-miscible liquid organic matter from said suspension.

11. The system of claim **10** wherein said plurality of cavitation jets are arranged on opposing walls of said cavitation vessel.

12. The system of claim **10** wherein said direction of flow defined by said inlet and outlet is vertical, said inlet is at an upper end of said vessel and said outlet is at a lower end of said vessel, and said cavitation jets are positioned on a vertical wall of said vessel.

13. The system of claim **10** wherein said cavitation vessel is a horizontal flow-through conduit with a horizontal axis, said direction of flow defined by said inlet and outlet is horizontal, and said cavitation jets are distributed around said axis and are directed toward said axis.

14. The system of claim **10** comprising a plurality of said cavitation vessels and a separatory vessel downstream of each cavitation vessel of said plurality.

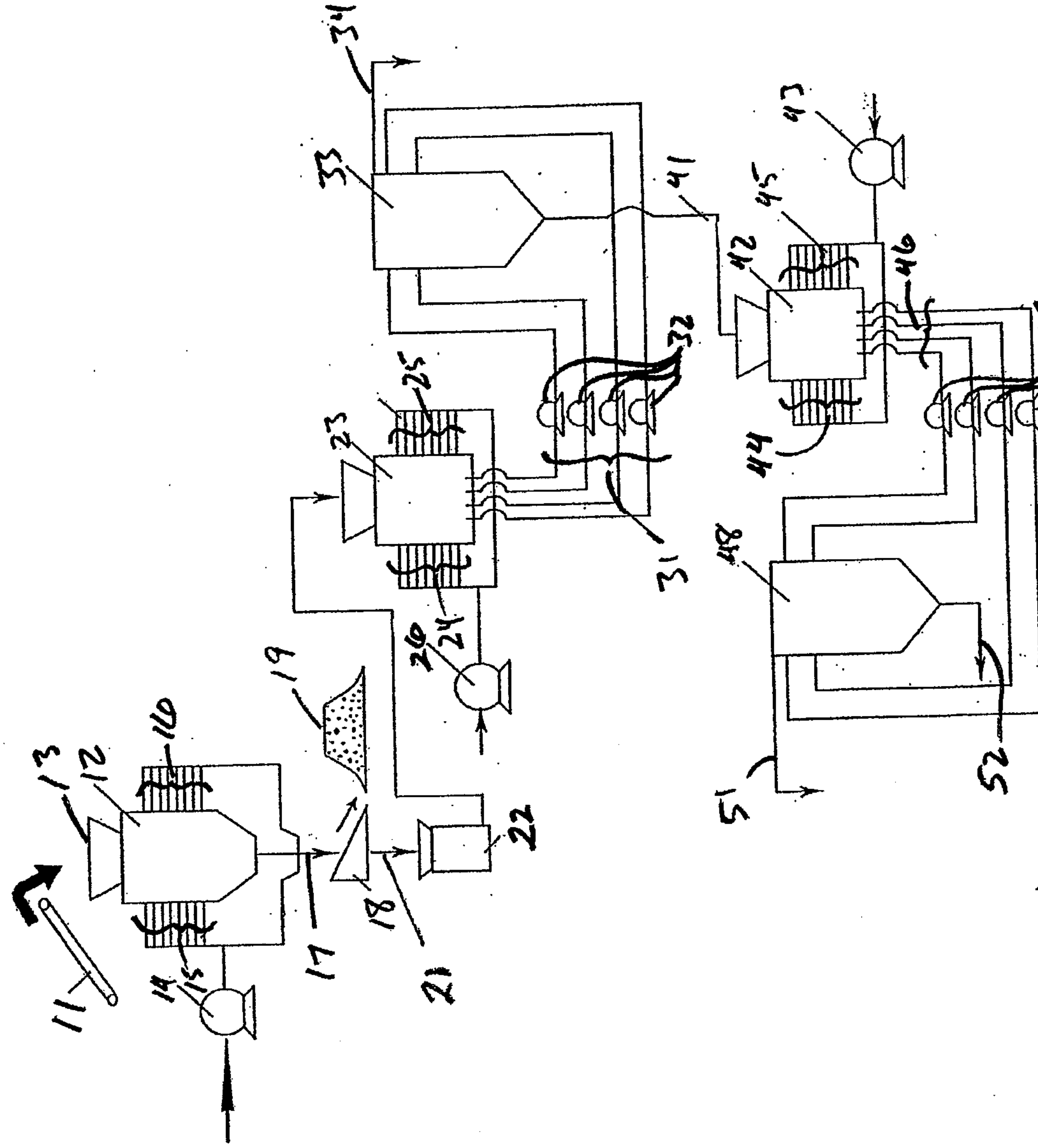

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FIG. 1

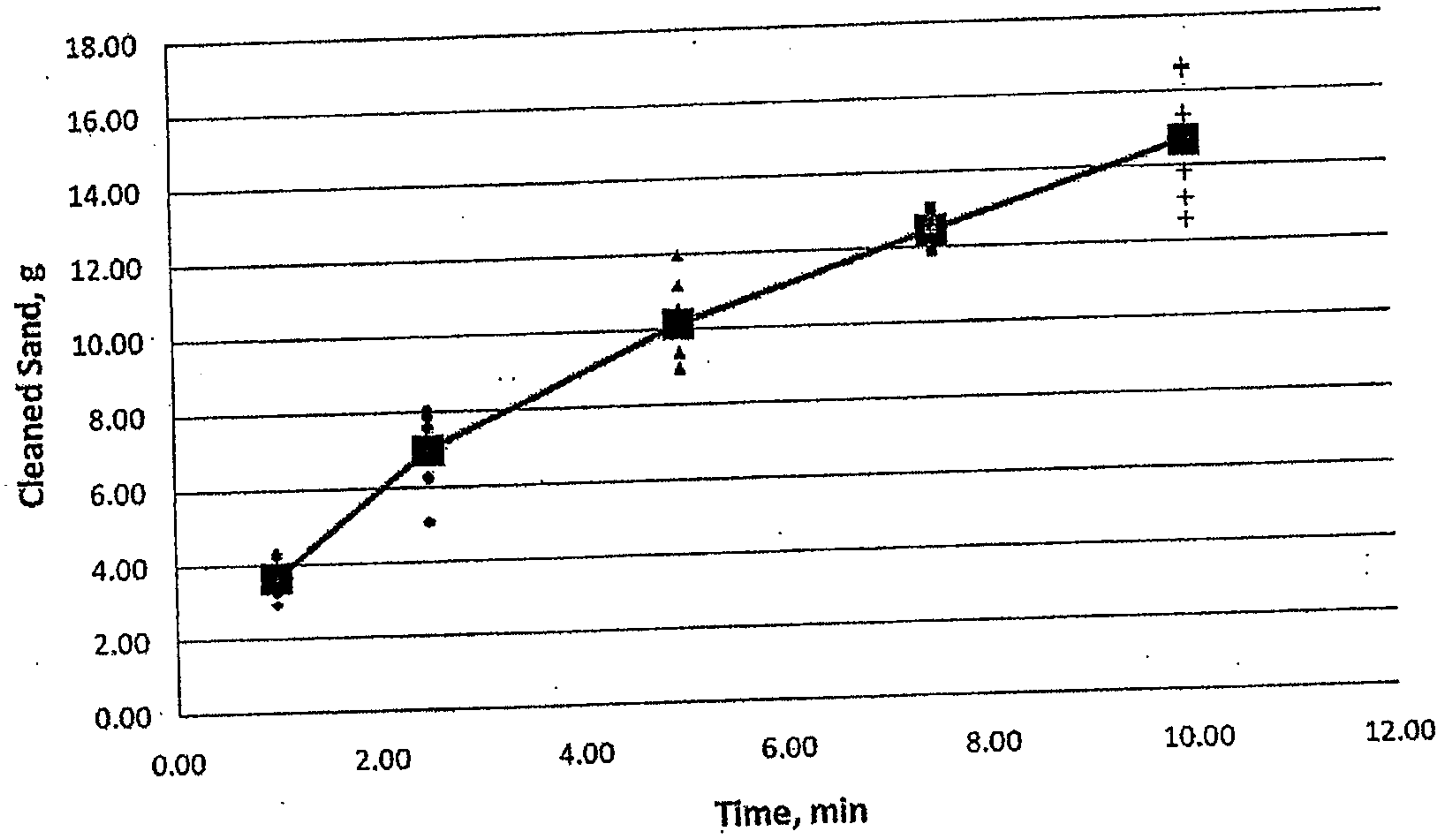
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FIG. 2

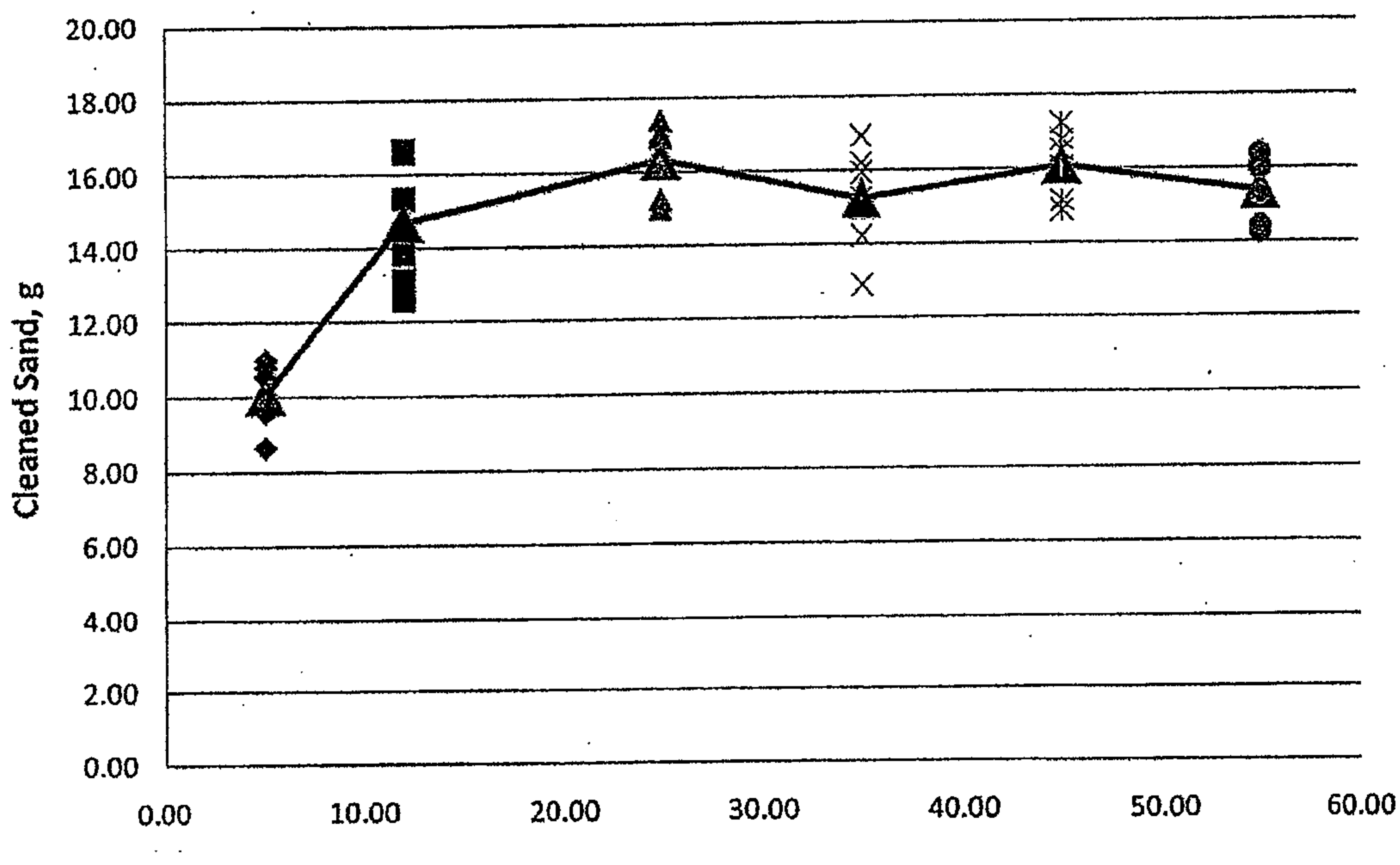
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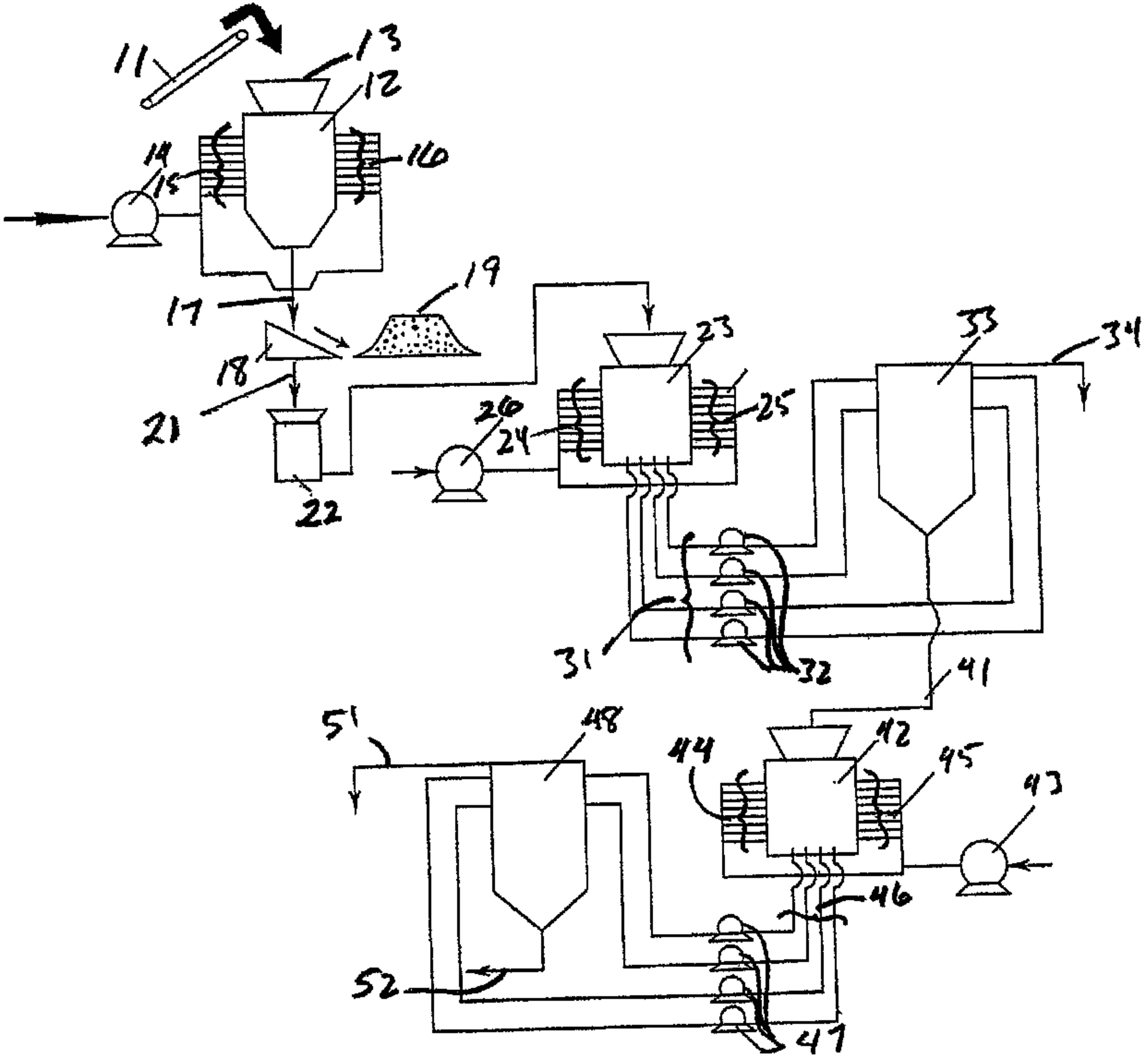
FIG. 3



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