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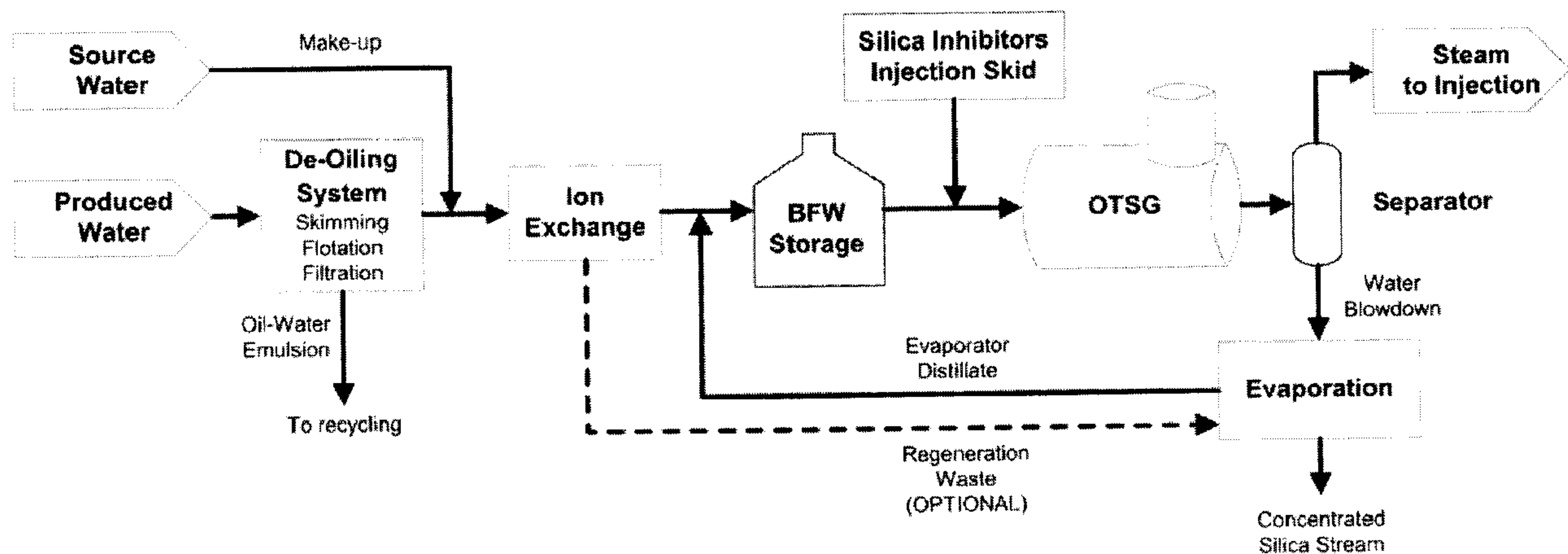
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(54) **Titre :** PROCEDE D'INHIBITION DU DEPOT DE SILICE ET D'EVAPORATION DU LIQUIDE DE PURGE (PROCEDE SIBE)

(54) **Title:** SILICA INHIBITION AND BLOWDOWN EVAPORATION (SIBE) PROCESS



(57) **Abrégé/Abstract:**

The invention relates to a method for producing steam from a silica containing feedwater. Feedwater containing silica is supplied to a boiler, generating a steam and a liquid blowdown. A silica desposition inhibitor is added to the feedwater prior to supplying the feedwater to the boiler. The liquid blowdown can be treated to produce a diluent water stream. The diluent water stream is added to the feedwater prior to supplying the feedwater to the boiler wherein the silica content of the diluent water stream is lower than the silica content of the feedwater to which it is added. The invention also relates to an installation adapted for implementing this method as well as to a method for extracting hydrocarbons from a subterranean formation making use of this method.



ABSTRACT

The invention relates to a method for producing steam from a silica containing feedwater. Feedwater containing silica is supplied to a boiler, generating a steam and a liquid blowdown. A silica desposition inhibitor is added to the
5 feedwater prior to supplying the feedwater to the boiler. The liquid blowdown can be treated to produce a diluent water stream. The diluent water stream is added to the feedwater prior to supplying the feedwater to the boiler wherein the silica content of the diluent water stream is lower than the silica content of the feedwater to which it is added. The invention also relates to an installation adapted for
10 implementing this method as well as to a method for extracting hydrocarbons from a subterranean formation making use of this method.

SILICA INHIBITION AND BLOWDOWN EVAPORATION (SiBE) PROCESS

FIELD OF THE INVENTION

5 Embodiments of the invention are related to processes for the treatment of boiler feed water to minimize scaling and more particularly to the removal of silica from boiler feed water used for steam generation for use in heavy oil extraction.

BACKGROUND OF THE INVENTION

10 As water is heated and converted into steam, contaminants brought into a boiler tend to be left in the boiler. The boiler functions as a distillation unit, taking pure water out as steam, and leaving behind concentrated minerals and other contaminants in the boiler. Scale forms as a result of the precipitation of normally soluble solids that become insoluble as temperature increases. Some
15 examples of boiler scale are calcium carbonate, calcium sulfate, and calcium silicate. Scale acts as an insulator, reducing boiler efficiency. Scaling can lead to boiler tube failure due to overheating.

 A variety of different methodologies have been employed to attempt to remove contaminants from boiler feed water including chemical precipitation such
20 as lime softening, ion exchange, reverse-osmosis, electrodialysis, distillation and freezing.

 Typically, large amounts of very high quality steam are required for in-situ heavy oil and oil sands recovery processes, such as steam assisted gravity

drainage (SAGD). There is an ever-increasing concern regarding the effects of such techniques on water supplies and on the discharge therefrom of water which may be heavily laden with said contaminants, such as large quantities of silica. There is great interest in recycling of water for use in the steam generation processes such as using boiler blowdown as at least a partial feed stream to a steam generator for the steam generation process.

Canadian Patent Application 2475048 to Total SA teaches use of silica inhibitors to reduce the need for a warm lime softening (WLS) process used to treat feedwater by about 25%. The reduction results in reduced costs due to reduced chemical requirements and increased boiler efficiency, particularly related to a once-through steam generator (OTSG). The addition of inhibitors to the water output from the WLS permits the product water from the WLS to have a higher silica content, the inhibitors being added to the product water prior to being introduced to the boiler. The silica inhibitors act to inhibit amorphous silica from polymerising into colloidal silica (groups of $\text{SiO}_2(\text{OH})_n$; where $n > 8$) which adheres to the boiler tubes creating silica scaling that may lead to tube failure.

There is an ongoing interest in the industry to reduce the capital expenditure and the overall operating costs associated with improving the quality of water used for steam generation for processes such as SAGD and which would permit at least some recycling of water in the processes, which would otherwise contain unacceptable levels of silica and other contaminants.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a schematic illustrating a method of steam generation according to an embodiment of the invention;

Figure 1B is a schematic illustrating an alternate method according to Fig. 1A;

Figure 2 is a schematic illustrating an embodiment according to Fig. 1A further comprising a crystallization unit;

Figure 3 is a graph illustrating silica composition evolution in the produced water of Example B of Table A over time;

Figure 4 is a schematic illustrating an embodiment of an evaporation/crystallization process for treating the blowdown stream; and

Figure 5 is a schematic illustrating a mass balance according to an embodiment of the invention.

15

SUMMARY OF THE INVENTION

The invention relates to a method for producing steam comprising:

- providing feedwater containing silica;
- supplying the feedwater to a boiler;
- adding an inhibitor of silica deposition to the feedwater prior to supplying the feedwater to the boiler;
- generating steam and a liquid blowdown in the boiler;
- treating at least part of the liquid blowdown to produce a diluent water stream;

- adding at least part of the diluent water stream to the feedwater before supplying the feedwater to the boiler;
- wherein the silica content of the diluent water stream is below the silica content of the feedwater to which it is added.

5 According to an embodiment, the inhibitor of silica deposition is selected from the group consisting of high molecular weight organic polymers such as derivatives of phosphovinyl-sulfonic acids and their salts, organic acids such as citric acid, maleic acid, formic acids, lactic acids, phosphino-carboxylic acids and their salts, inorganic compounds such as boric acid, hydrofluoric acid and their
10 salts, borax, sodium aluminates and sodium chlorates, as well as mixtures thereof.

 According to an embodiment, the boiler is a once through steam generator.

 According to an embodiment, the boiler generates approximately 1-50 wt% liquid blowdown and 50-99 wt% steam, preferably approximately 5-40 wt%
15 liquid blowdown and 60-95 wt% steam, most preferably approximately 15-30 wt% liquid blowdown and 70-85 wt% steam.

 According to an embodiment, the treatment of the liquid blowdown is performed by decantation and/or by evaporation and/or crystallization.

 According to an embodiment:

- 20 – the silica content of the feedwater prior to addition of the diluent water stream is equal to or less than approximately 400 mg/L, preferably is approximately comprised between 300 and 400 mg/L,

most preferably is approximately comprised between 333 and 400 mg/L; and/or

- the silica content of the liquid blowdown prior to treatment is above approximately 400 mg/L, preferably above approximately 1000 mg/L, most preferably above approximately 1600 mg/L; and/or
- the silica content of the diluent water stream is below approximately 200 mg/L, preferably below approximately 50 mg/L, and most preferably the diluent water stream is substantially silica-free.

According to an embodiment, there is no reduction of the silica content of the feedwater prior to adding the diluent water stream, and there is no reduction of the silica content of the feedwater after adding the diluent water stream.

According to an embodiment, the abovementioned method comprises storing the feedwater in a storage tank prior to supplying it to the boiler.

According to an embodiment, the inhibitor of silica deposition is added to the feedwater after storing the feedwater in the storage tank and before supplying to the boiler.

According to an embodiment, the inhibitor of silica deposition is added to the feedwater before storing the feedwater in the storage tank.

According to an embodiment, the abovementioned method comprises reducing the hardness of the feedwater prior to supplying it to the boiler, and preferably prior to storing the feedwater in the storage tank.

According to an embodiment, the treatment of the liquid blowdown is performed by decantation and the diluent water stream is added to the feedwater before reducing the hardness of the feedwater.

5 According to an embodiment, the treatment of the liquid blowdown is performed by evaporation and/or crystallization and the diluent water stream is added to the feedwater after reducing the hardness of the feedwater.

According to an embodiment, the feedwater is produced water from heavy oil recovery processes, such as steam assisted gravity drainage, said produced water being preferably de-oiled.

10 The invention also relates to an installation for producing steam comprising:

- a boiler;
- a feedwater supply system connected to an inlet of the boiler;
- an inhibitor of silica deposition supply system, an outlet of which is
15 connected to the feedwater supply system;
- a steam conduit connected to an outlet of the boiler;
- a liquid blowdown conduit connected to an outlet of the boiler; and
- a treatment unit for reducing the silica content of water, an inlet of
which is connected to the liquid blowdown conduit and an outlet of
20 which is connected to the feedwater supply system.

According to an embodiment, the boiler is a once through steam generator.

According to an embodiment, the treatment unit comprises a decanter and/or an evaporator and/or a crystallizer.

According to an embodiment, the abovementioned installation does not comprise any lime softening unit.

5 According to an embodiment, the feedwater supply system comprises a hardness reducing unit, which is preferably an ion exchange system.

According to an embodiment, the treatment unit comprises a decanter and the outlet of the treatment unit is connected to the feedwater supply system upstream the hardness reducing unit.

10 According to an embodiment, the treatment unit comprises an evaporator and/or a crystallizer and the outlet of the treatment unit is connected to the feedwater supply system downstream the hardness reducing unit.

According to an embodiment, the feedwater supply system comprises a feedwater storage tank.

15 According to an embodiment, the outlet of the inhibitor of silica deposition supply system is connected to the feedwater supply system upstream the feedwater storage tank.

 According to an embodiment, the outlet of the inhibitor of silica deposition supply system is connected to the feedwater supply system downstream
20 the feedwater storage tank.

The invention also relates to a process for extracting hydrocarbons from a subterranean formation comprising:

- producing steam according to the abovementioned method;

- injecting the produced steam into at least one injection well;
- recovering hydrocarbons and produced water from at least one extraction well;
- de-oiling the produced water and using the de-oiled produced water as feedwater in the steam production method.

Hydrocarbons which may be extracted according to the present invention include in particular bitumen and heavy oils.

DESCRIPTION OF EMBODIMENTS

The invention will now be described in more detail without limitation in the following description.

Embodiments of the invention permit boiler feedwater having an increased silica content to be used to produce steam in a boiler such as a conventional boiler or a once through steam generator (OTSG) as a result of the combination of the addition of silica inhibitors to the water entering the conventional boiler or the OTSG and the effect of adding a substantially silica free or reduced silica stream of water to the feedwater. An OTSG has a lower steam yield than a conventional boiler. Embodiments of the invention eliminate the prior art requirements for treatment of the feedwater with warm lime softening and also reduce scaling in the boiler. One source of feedwater for steam production is produced water from heavy oil recovery processes, such as steam assisted gravity drainage (SAGD), the produced water having been de-oiled following production using conventional technology. A SAGD recovery process typically comprises at

least one injection well and at least one extraction well. Steam is injected through the at least one injection well for recovering hydrocarbons and produced water from the at least one extraction well.

In an embodiment of the invention, the permissible silica content of the feedwater directed to the conventional boiler or to the OTSG can be increased from
5 an upper limit of about 100 mg/L known in the prior art for conventional boiler processes, to about 333 mg/L in embodiments utilizing a recycling of about 20% blowdown from an OTSG. Further, Applicant believes the maximum permissible silica content, according to some embodiments of the invention, may be as high as
10 about 400 mg/L with a 20% to 25% blowdown. Increased dilution with silica-free water from the evaporator or increased amounts of inhibitor or a combination of the two may be used if silica concentrations in the produced water exceed 400 mg/L.

In an embodiment of the invention (Fig. 1A), an installation comprising a feedwater supply system is connected to the inlet of a conventional boiler or
15 OTSG. The feedwater supply system can comprise a de-oiling system, an ion exchange unit or ion exchange system, and a boiler feedwater storage tank. The ion exchange unit can serve as a hardness reducing unit.

Blowdown from the conventional boiler or OTSG has a high silica content and can be flowed to a silica treatment unit, such as a blowdown
20 evaporator, for reducing the silica content of water. An inlet of the silica treatment unit is connected to the liquid blowdown and an outlet of which is connected to the feedwater supply system. A distillate water produced from the evaporator provides a substantially silica free diluent water stream which is recycled into the feedwater

stream following an ion exchange unit or before the ion exchange unit and prior to or after the addition of the silica inhibitors. Thus, embodiments of the process permit recycling of the blowdown water.

In another embodiment of the invention (Fig. 1B), a substantially silica-free water from a source other than the evaporator is added to the feedwater stream for diluting the feedwater stream.

Optionally, as shown in Fig. 2, a combined evaporation and crystallization unit may be used to permit land-filling of the silica and other contaminants produced by the evaporation process.

As an alternative to the evaporation and optionally crystallization unit, or in addition to that unit, use may be made of a decanter wherein solid silica, as well as other suspended solids, is separated from the bulk of the liquid blowdown owing to gravity. When only a decanter is used for converting the liquid blowdown to the diluent water stream, the diluent water stream must generally be added to the feedwater upstream the ion exchange unit. When an evaporation (and optionally crystallization) unit is used for converting the liquid blowdown to the diluent water stream, the diluent water stream can generally be added to the feedwater downstream the ion exchange unit, since the evaporator removes hardness as well as silica.

Having reference to Figs. 1A and 1B, and in an embodiment of the invention, such as in a process for extracting hydrocarbons from a subterranean formation, a high quality steam is produced, for injection through at least one injection well and into a heavy oil or bitumen deposit using the conventional boiler or

the once-through steam generator (OTSG). Steam is produced from a steam conduit connected to a first outlet of the boiler. Desired steam quality is typically greater than 70% and more preferably greater than 75%. Feedwater for the process is typically de-oiled produced water from a recovery wellbore. The produced water is typically de-oiled using conventional technology. Hydrocarbons and produced water are recovered from at least one extraction well.

Table A illustrates typical ionic constituents of samples of produced water from three different SAGD operations.

TABLE A

	EXAMPLE A	EXAMPLE B	EXAMPLE C	
CATIONS	mg/l	mg/l	mg/l	
Sodium, Na ⁺	2200.0	706.0	780.0	
Calcium, Ca ²⁺	2.7	3.9	22.0	
Magnesium, Mg ²⁺	6.1	0.3	11.0	
Barium, Ba ²⁺	0.0	0.2	0.0	
Potassium, K ⁺	62.0	28.7	13.0	
Iron, Fe ²⁺	1.9	0.7	0.3	
Total Cations	2273.0	740.0	826.3	
ANIONS	mg/l	mg/l	mg/l	
Chloride, Cl ⁻	1697.0	930.0	962.0	
Sulfate, SO ₄ ²⁻	56.0	1.0	58.0	
Carbonate, CO ₃ ²⁻	108.0	1.0	0.0	
Bicarbonate, HCO ₃ ⁻	2677.0	332.0	489.0	
Total Anions	4538.0	1264.0	1509.0	
Total Dissolved Solids:	6951.0	2370.0	2585.0	
Hardness (Ca ²⁺ , Mg ²⁺)	32.0	11.0	100.9	mg/l as CaCO ₃
pH (25°C):	7.9	8.0	7.7	
Silica	260.0	260.0	250.0	mg/l

10

Fig. 3 illustrates the silica composition evolution in the produced water of Example B over time. According to this graph, the maximum value of silica achieved is about 400 mg/l.

Having reference to Figs. 1A, 1B and 2, the produced, de-oiled water is mixed with sufficient make-up water to meet the feedwater demands of the conventional boiler or the OTSG. The combined stream of produced water and makeup water is passed through the ion exchange unit comprising an ion exchange resin, in many cases a weak acid cation exchange resin (WAC), for demineralization of the feed water and typically also for removal of hardness which may aid in reducing the amount of blowdown required from the boiler. Removal of Ca^{2+} and Mg^{2+} ions further prevents the formation of silicates therewith which form deposits in the boiler. The diluted, treated feedwater is typically stored in a storage tank for use in the conventional boiler or the OTSG.

An injection skid or other suitable means, as an inhibitor of silica deposition supply system, is typically positioned downstream from the diluted, treated feedwater storage and upstream from the conventional boiler or the OTSG for the addition of silica inhibitors as described in Canadian Patent Application 2,475,048 to Total SA. Alternatively, this injection skid may be positioned anywhere upstream the boiler, i.e. either upstream or downstream the feedwater storage, either upstream or downstream the ion exchange unit (if present), either upstream or downstream the addition of diluent water stream. A liquid blowdown conduit, connected to a second outlet of the boiler, typically from a separator used to separate water and steam produced from the conventional boiler or OTSG, is directed to an evaporator where the blowdown water is distilled to produce a substantially silica free distillate stream and a concentrated silica waste stream which is discharged therefrom.

Certain low molecular weight organic acids, certain alcohols, and ions, such as fluorides, borates and the like, as well as specific conditions such as alkaline or very acidic pH are known to deteriorate glass and silicates. In embodiments of the invention, the inhibitors of silica deposition used are selected
5 from among compound families known to inhibit the deposition of silica carbonates. Preferably, the compounds used include high molecular weight organic polymers such as derivatives of phospho-vinyl-sulphonic acids and their salts; organic acids such as citric acid, maleic acid, formic acids, lactic acids, phosphino-carboxylic acids, and their salts; inorganic compounds such as boric acid, hydrofluoric acid
10 and their salts; borax, sodium aluminates and sodium chlorates. The compounds are used alone or in mixtures thereof.

In an embodiment of the invention, the inhibitor comprises a combination of organic inhibitors utilizing phosphor-vinylsulfonic acid or a polyvinylsulfonate as the principal active ingredient in combination with a mixture of
15 one or more organic acids, typically citric acid, maleic acid, formic acid or lactic acid. Further, salts of the organic acids may be used to maintain a pH closer to neutrality. Ammonium salts of formic acid and citric acid are not used.

In one embodiment of the invention, citric acid and maleic acid are added to phosphovinylnsulfonic acid to obtain a thermally stable inhibitor. In one
20 embodiment, the weight ratio of citric acid to maleic acid is about 10/1, the % by weight of citric acid being between about 3% to about 10% and preferably about 5%.

The inhibitors, used alone or in combination, act to prevent the

coalescence of monomers of $(\text{OH})_3\text{-Si-O-Si(OH)}_3$, and leave polymers of $\text{SiO}_2(\text{OH})_n$, wherein n is equal to less than 8, in suspension. The inhibitors are capable of performing inhibition functions at temperature of 300°C or greater which is particularly advantageous when used for steam generation in amounts ranging in
5 some embodiments from between about 2 ppm to about 2000 ppm, in some embodiments from between about 3 ppm to about 100 ppm and in some embodiments from about 5 ppm to about 50 ppm. Use of the inhibitors, according to embodiments described in Canadian Application 2475048 to Total SA, permits the use of feedwater recycled from blowdown and having silica concentrations which
10 are 4 to 5 times the permissible concentration known in the prior art without substantial silica deposition in the conventional boiler or the OTSG.

The amount of inhibitor used may be determined depending upon the pH of the feedwater as pH controls the solubility of silica, the silica being more soluble in very alkaline conditions or in certain acidic conditions, such as in the presence of
15 some acids, such as hydrofluoric acid. Having reference to Figs. 1A and 2 and in embodiments of the invention, approximately 20 to 25% of the total water output from the boiler is recycled as a substantially silica-free distillate stream and is added to the feedwater stream downstream from the ion exchange. In embodiments of the invention, the amount of total water output from the boiler that is recycled may be
20 increased to about 40% as required.

Having reference to Fig. 1B, substantially silica free water from a source other than a recycle evaporator is added to the feedwater stream downstream from the ion exchange.

The feedwater is diluted so as to reduce the silica concentration in the feedwater such that, in combination with the addition of inhibitors according to embodiments of the invention and without the need for warm lime softening, there is a significant reduction in deposition of silica in the conventional boiler or in the OTSG. Thus, embodiments of the invention achieve substantial inhibition of silica deposition in a cost effective manner.

In embodiments of the invention therefore, a method is provided for producing steam from feedwater containing silica comprising receiving a substantially oil-free feedwater stream, treating the feedwater stream with ion exchange for substantially reducing the concentration of ions contributing to hardness of the feedwater, introducing a substantially silica-free stream to the feedwater for diluting the feedwater for reducing the silica concentration therein, adding an effective amount of inhibitors for minimizing formation of colloidal silica and generating steam and a blowdown water from the feedwater in a conventional boiler or in a once through steam generator OTSG, the blowdown water being subsequently evaporated or concentrated for producing at least a concentrated silica stream for disposal thereof.

In embodiments of the invention, the substantially silica-free stream which is recycled to the feedwater stream is produced by the evaporation or concentration of the blowdown water.

Applicant believes that the maximum silica concentration in produced water is typically about 400 mg/L or less and the dilution of the feedwater, being the

substantially de-oiled produced water, results in a silica concentration entering the boiler of about 333 mg/L or less.

In embodiments of the invention, the effective amount of inhibitor is typically determined dependent upon the pH of the feedwater.

5 For example, as shown in Figs. 1A, 1B and 2, the effect of the dilution of the feedwater stream reduces the silica concentration in a produced/de-oiled water from a maximum of about 400 mg/L to a maximum of about 333 mg/L and therefore the inhibitors added downstream are required to inhibit a maximum of about 333 mg/l of silica in the boiler feedwater. Additional WLS is therefore not
10 required as the process according to embodiments of the invention, which combine inhibitors and dilution of the feedwater, is capable of handling initial feed streams having higher silica concentrations without scale buildup. Similarly, according to the present invention, there is preferably no treatment of the feedwater in an evaporator either.

15 Further, water can be routed directly from the ion exchange regeneration to the evaporator for distillation for forming at least a portion of the substantially silica-free stream which is subsequently recycled to the feedwater stream downstream from the ion exchange.

Embodiments of the invention are limited to produced and source or
20 make-up water having a hardness below about 200 mg/L as CaCO_3 and more preferably below about 100 mg/L. Preferably, the produced water also has a low salinity, having a total dissolved solids (TDS) content of less than about 10,000 mg/L.

As shown in Fig. 2 and in an embodiment of the invention, the concentrated silica stream from the evaporator may be directed to a crystallization unit wherein the concentrated silica stream, produced by evaporation, is crystallized for disposal in landfill or other suitable disposal site.

5 Having reference to Fig. 4, a conventional evaporation/crystallization process is shown for processing the blowdown stream.

 Having reference to Fig. 5 and in an example of an embodiment of the invention, a feedwater from an ion exchange, having a silica concentration of less than or equal to 400 mg/L, is diluted with a substantially silica-free diluent stream
10 derived from the evaporator as evaporator blowdown, the resulting diluted feedwater stream having a concentration of less than or equal to 333 mg/L silica. The diluted feedwater is stored for use in the conventional boiler or the OTSG. Inhibitors are added upstream from the conventional boiler or the OTSG in an amount sufficient to inhibit about 270 mg/L of silica for preventing deposition in the
15 conventional boiler or the OTSG, the remaining 63 mg/L silica being within the tolerance limits of the conventional boiler or the OTSG. The produced steam and water from the boiler is passed to a separator which separates the steam from the water containing impurities. Approximately 20-25% of the water blown down to an evaporator wherein the blowdown stream is further distilled to a silica-free distillate
20 for recycling to the feedwater as diluent and a highly silica-concentrated stream which is crystallized or otherwise treated for disposal.

 Optionally, a freezing crystallization unit (not shown) may replace the evaporation crystallization unit.

1 CLAIMS

2 1. A method for producing steam comprising:
3 providing feedwater containing silica;
4 supplying the feedwater to a boiler;
5 adding an inhibitor of silica deposition to the feedwater prior to
6 supplying the feedwater to the boiler;
7 generating steam and a liquid blowdown in the boiler;
8 treating at least part of the liquid blowdown to produce a diluent water
9 stream;
10 adding at least part of the diluent water stream to the feedwater before
11 supplying the feedwater to the boiler; and
12 wherein the silica content of the diluent water stream is below the
13 silica content of the feedwater to which it is added.

14

15 2. The method of claim 1, wherein the inhibitor of silica deposition
16 is selected from the group consisting of high molecular weight organic polymers,
17 organic acids, inorganic compounds, borax, sodium aluminates, sodium chlorates
18 and mixtures thereof.

19

20 3. The method of claim 2, wherein the high molecular weight
21 organic polymers are derivatives of phosphovinyl-sulfonic acids and their salts.

22

1 4. The method of claim 2, wherein the organic acids are citric acid,
2 maleic acid, formic acids, lactic acids, phosphino-carboxylic acids, or their salts.

3

4 5. The method of claim 2, wherein the organic compounds are
5 boric acid, hydrofluoric acid, or their salts.

6

7 6. The method of any one of claims 1 to 5 wherein the boiler is a
8 once through steam generator.

9

10 7. The method of any one of claims 1 to 6, wherein the boiler
11 generates approximately 1-50 wt% liquid blowdown and 50-99 wt% steam.

12

13 8. The method of any one of claims 1 to 6, wherein the boiler
14 generates approximately 5-40 wt% liquid blowdown and 60-95 wt% steam.

15

16 9. The method of any one of claims 1 to 6, wherein the boiler
17 generates approximately 15-30 wt% liquid blowdown and 70-85 wt% steam.

18

19 10. The method of any one of claims 1 to 9, wherein the treatment
20 of the liquid blowdown is performed by decantation or by evaporation or
21 crystallization or a combination thereof.

22

23

1 11. The method of any one of claims 1 to 10, wherein:
2 the silica content of the feedwater prior to addition of the diluent water
3 stream is equal to or less than approximately 400 mg/L.

4
5 12. The method of any one of claims 1 to 10, wherein the silica
6 content of the feedwater prior to addition of the diluent water stream is from
7 approximately 300 mg/L to approximately 400 mg/L.

8
9 13. The method of any one of claims 1 to 10, wherein the silica
10 content of the feedwater prior to addition of the diluent water stream is from
11 approximately 333 mg/L to approximately 400 mg/L.

12
13 14. The method of any one of claims 1 to 13, the silica content of
14 the liquid blowdown prior to treatment is above approximately 400 mg/L.

15
16 15. The method of any one of claims 1 to 13, the silica content of
17 the liquid blowdown prior to treatment is above approximately 1000 mg/L.

18
19 16. The method of any one of claims 1 to 13, the silica content of
20 the liquid blowdown prior to treatment is above approximately 1600 mg/L.

21
22 17. The method of any one of claims 1 to 16, the silica content of
23 the diluent water stream is below approximately 200 mg/L.

1 18. The method of any one of claims 1 to 16, the silica content of
2 the diluent water stream is below approximately 50 mg/L.

3

4 19. The method of any one of claims 1 to 16, wherein the diluent
5 water stream is substantially silica-free.

6

7 20. The method of any one of claims 1 to 19, comprising storing the
8 feedwater in a storage tank prior to supplying it to the boiler.

9

10 21. The method of claim 20, wherein the inhibitor of silica
11 deposition is added to the feedwater after storing the feedwater in the storage tank
12 and before supplying to the boiler.

13

14 22. The method of claim 20, wherein the inhibitor of silica
15 deposition is added to the feedwater before storing the feedwater in the storage
16 tank.

17

18 23. The method of any one of claims 1 to 22, further comprising
19 reducing the hardness of the feedwater prior to supplying it to the boiler.

20

21 24. The method of claims 20, 21 or 22 further comprising reducing the
22 hardness of the feedwater prior to storing the feedwater in the storage tank.

23

1 25. The method of claims 23 or 24, wherein the treatment of the
2 liquid blowdown is performed by decantation and the diluent water stream is added
3 to the feedwater before reducing the hardness of the feedwater.

4

5 26. The method of claims 23 or 24, wherein the treatment of the
6 liquid blowdown is performed by evaporation or crystallization or combination
7 thereof, and the diluent water stream is added to the feedwater after reducing the
8 hardness of the feedwater.

9

10 27. The method of any one of claims 1 to 26, wherein the
11 feedwater is produced water from a heavy oil recovery process.

12

13 28. The method of claim 27, wherein the heavy oil recovery process is
14 steam assisted gravity drainage.

15

16 29. The method of claims 27 or 28, wherein the produced feedwater is
17 de-oiled.

18

19

1 30. An installation for producing steam comprising:
2 a boiler;
3 a feedwater supply system connected to an inlet of the boiler;
4 an inhibitor of silica deposition supply system, an outlet of which is
5 connected to the feedwater supply system;
6 a steam conduit connected to an outlet of the boiler;
7 a liquid blowdown conduit connected to the outlet of the boiler; and
8 a silica treatment unit for reducing the silica content of water, an inlet
9 of which is connected to the liquid blowdown conduit and an outlet of which is
10 connected to the feedwater supply system.

11

12 31. The installation of claim 30, wherein the boiler is a once
13 through steam generator.

14

15 32. The installation of claim 30 or 31, wherein the silica treatment
16 unit comprises a decanter or an evaporator or a crystallization unit or a combination
17 thereof.

18

19 33. The installation of claim 30 or 31, wherein the feedwater supply
20 system comprises a hardness reducing unit.

21

22 34. The installation of claim 33 wherein the hardness reducing unit is
23 an ion exchange system.

1 35. The installation of claim 33 or 34, wherein the silica treatment
2 unit comprises a decanter and the outlet of the silica treatment unit is connected to
3 the feedwater supply system upstream of the hardness reducing unit.

4

5 36. The installation of claim 33 or 34 wherein the silica treatment
6 unit comprises an evaporator or a crystallization unit or a combination thereof, and
7 the outlet of the silica treatment unit is connected to the feedwater supply system
8 downstream of the hardness reducing unit.

9

10 37. The installation of any one of claims 30 to 36, wherein the
11 feedwater supply system comprises a feedwater storage tank.

12

13 38. The installation of claim 37, wherein the outlet of the inhibitor of
14 silica deposition supply system is connected to the feedwater supply system
15 upstream of the feedwater storage tank.

16

17 39. The installation of claim 37, wherein the outlet of the inhibitor of
18 silica deposition supply system is connected to the feedwater supply system
19 downstream of the feedwater storage tank.

20

21

1 40. A process for extracting hydrocarbons from a subterranean
2 formation comprising:
3 producing steam according to the method of any one of claims 1 to 29;
4 injecting the produced steam into at least one injection well;
5 recovering hydrocarbons and produced water from at least one
6 extraction well; and
7 de-oiling the produced water and using the de-oiled produced water
8 as feedwater in the steam production process.
9

Fig. 1A

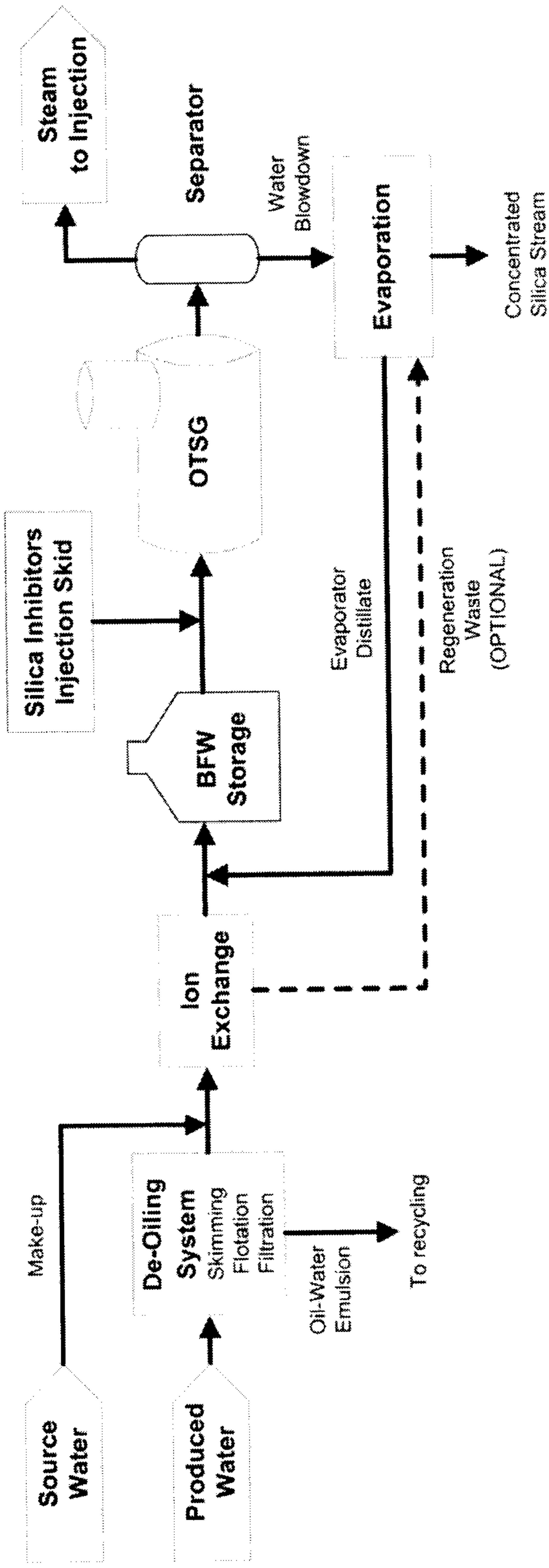


Fig. 1B

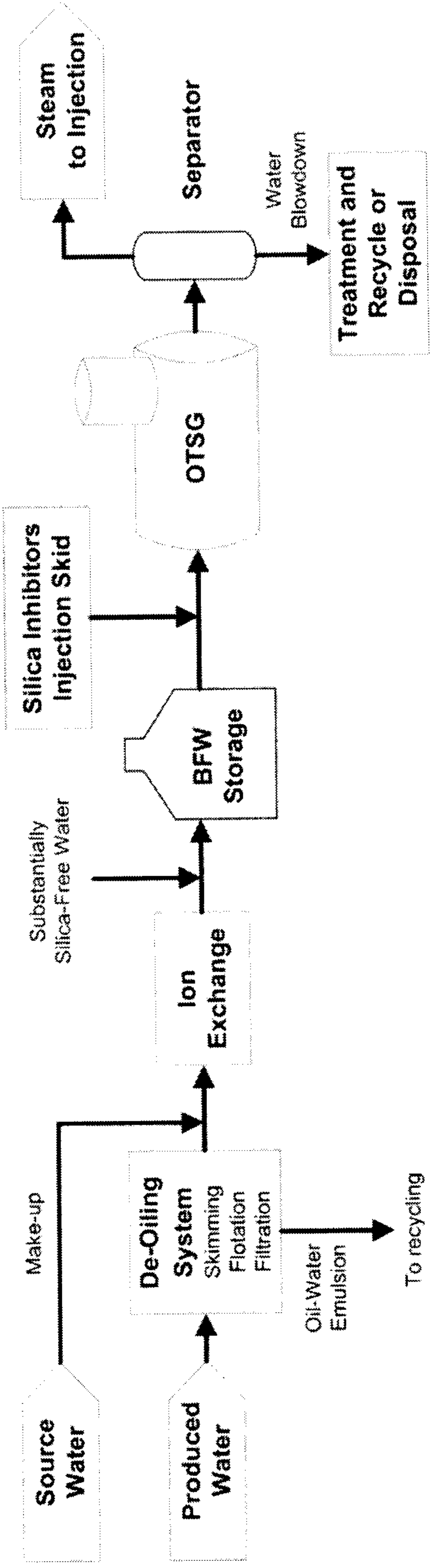
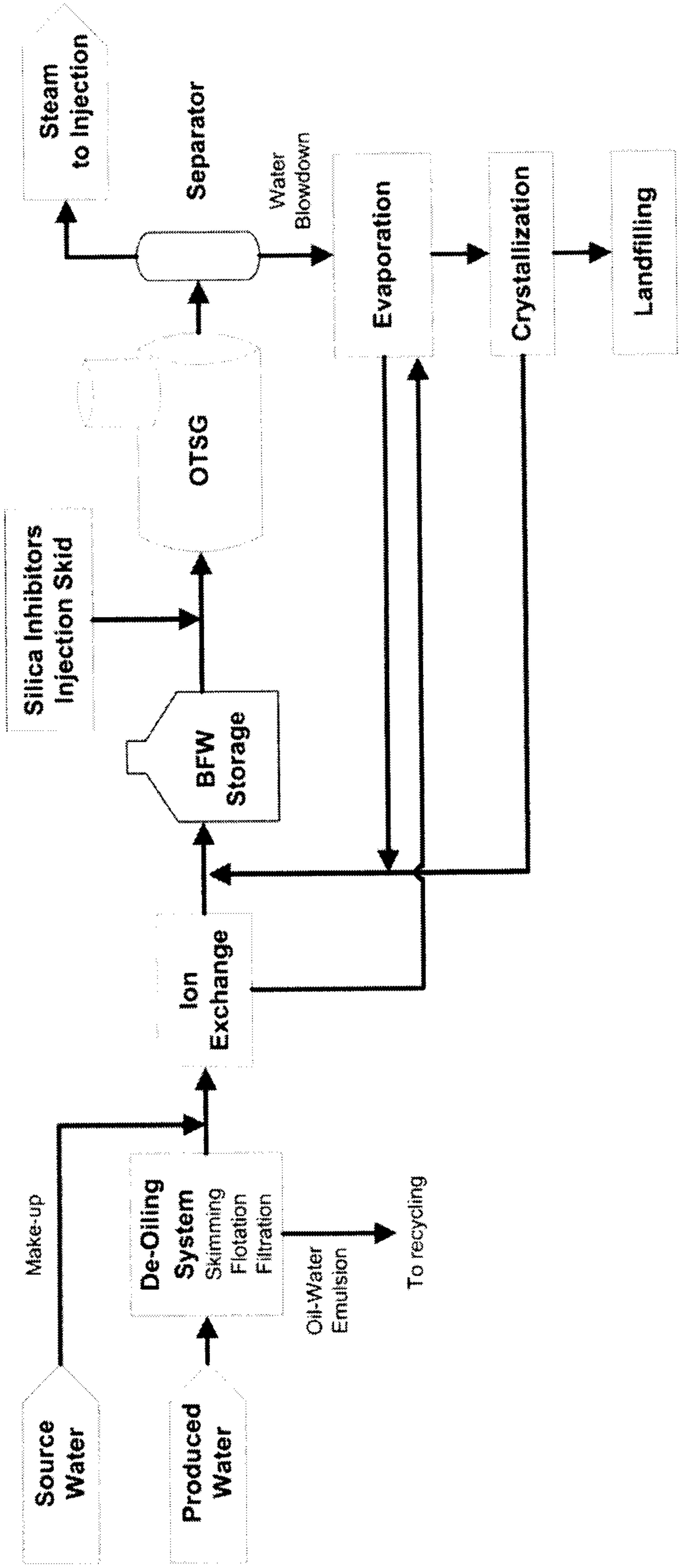


Fig. 2



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Fig. 3

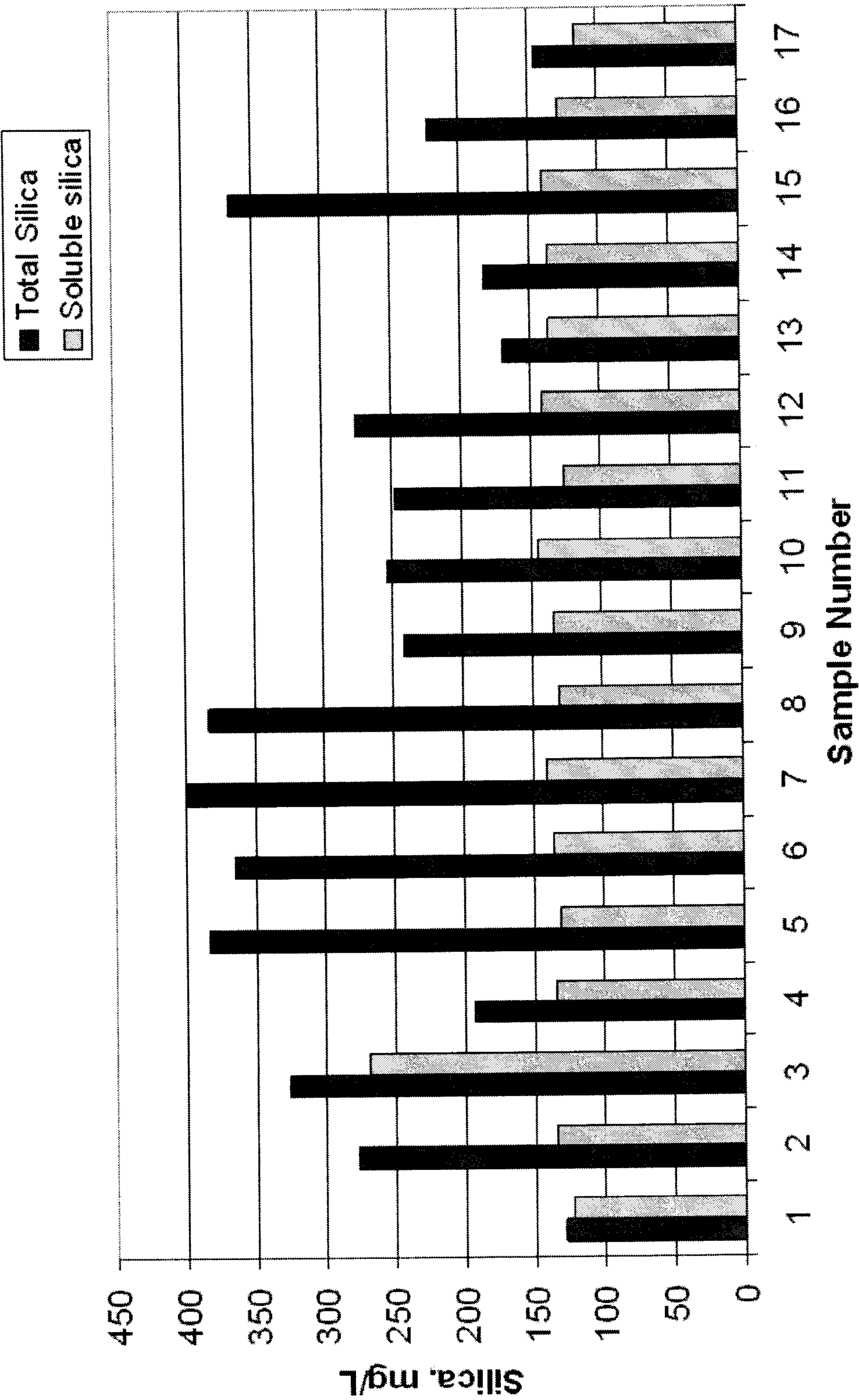


Fig. 4

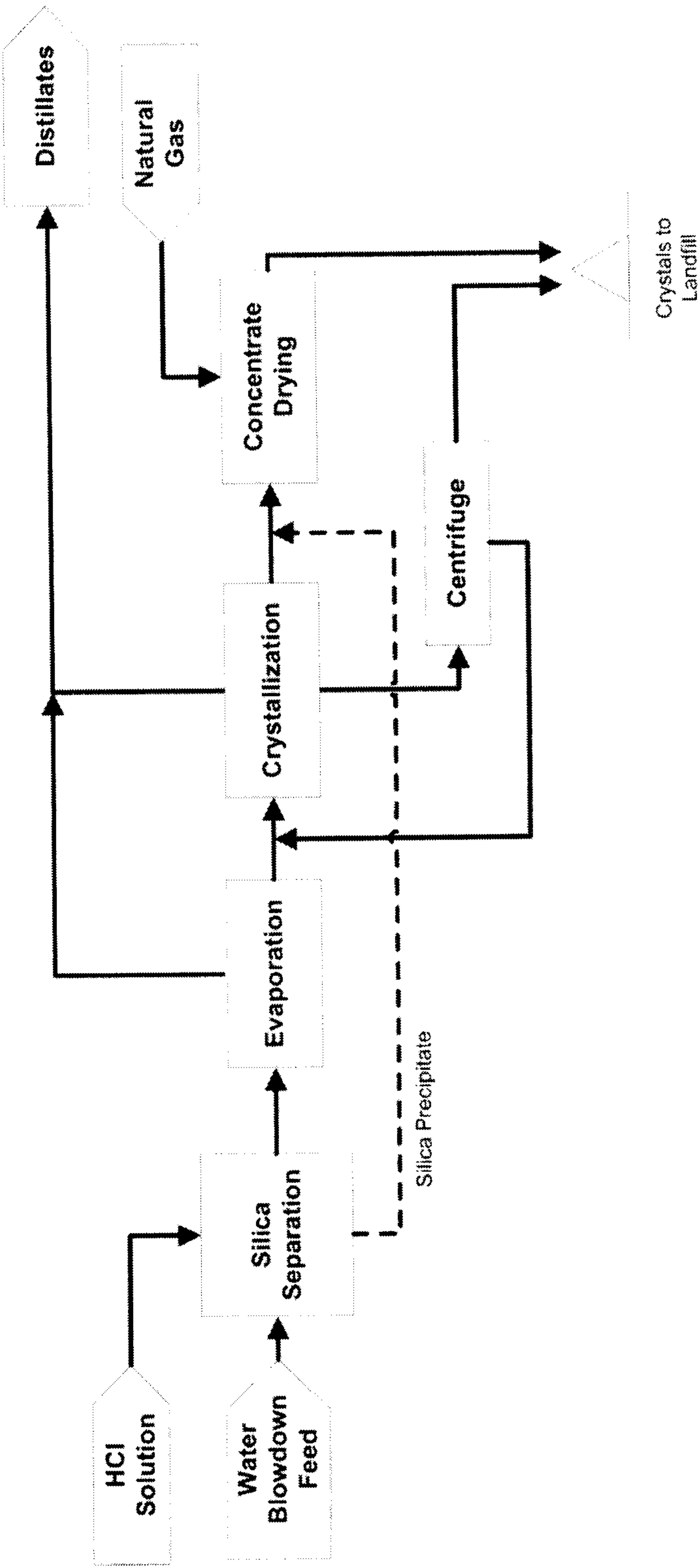


Fig. 5

