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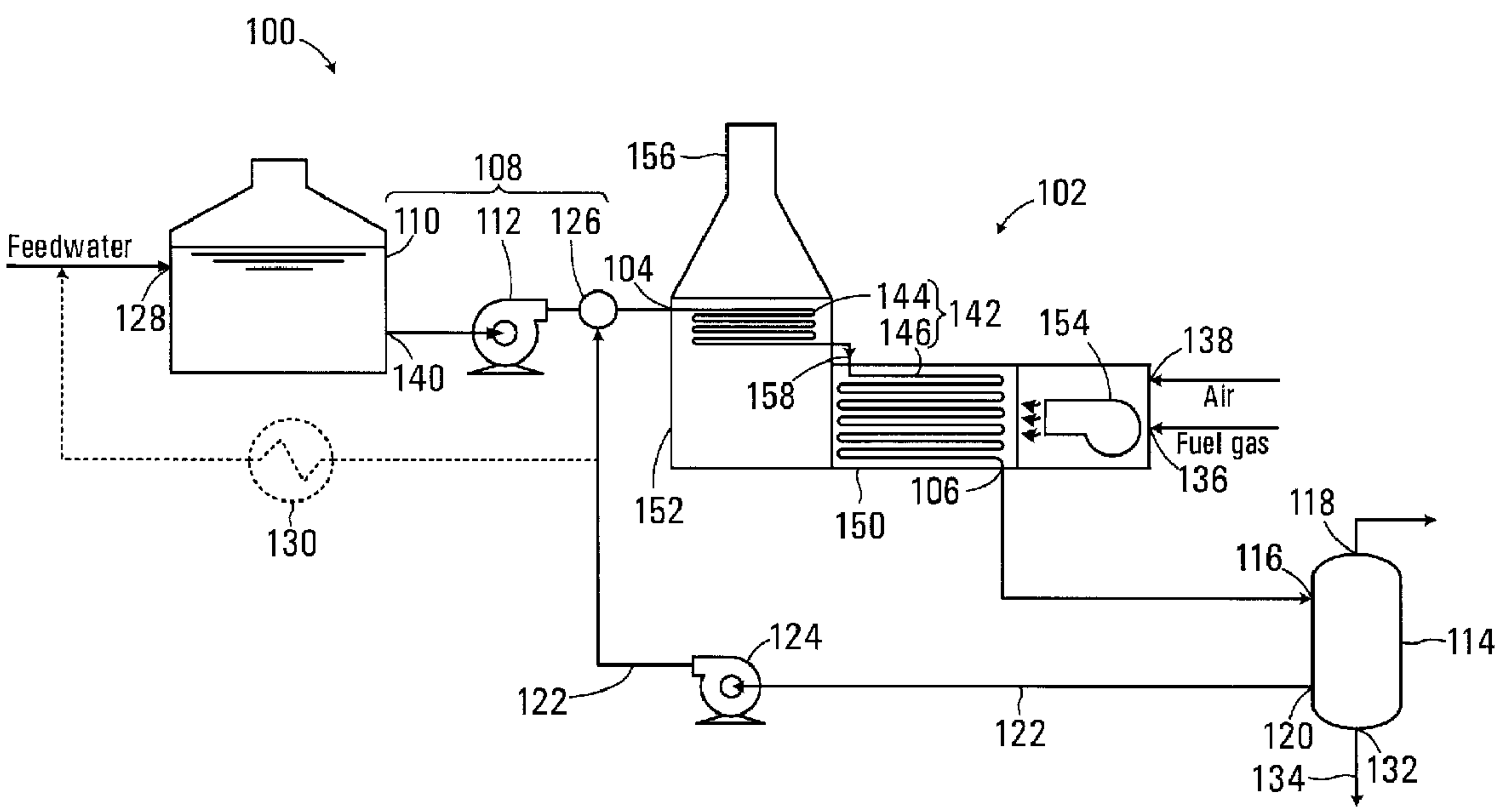
(54) Title: METHOD AND SYSTEM FOR GENERATING STEAM FROM A FEEDWATER STREAM INCLUDING IMPURITIES



(57) Abrégé/Abstract:
A method and system for generating steam from a feedwater stream including impurities is disclosed. The system includes a steam generator having an inlet for receiving the feedwater stream and an outlet for producing an outlet stream. The steam generator is

(57) Abrégé(suite)/Abstract(continued):
operable to cause vaporization of feedwater to generate the outlet stream including a steam portion having a lesser mass proportion than a remaining liquid phase portion. The system also includes a feed apparatus operable to deliver the feedwater stream to the inlet of a steam generator at a sufficiently high flow rate to reduce scaling within the steam generator. The system further includes a separator operable to separate at least a portion of the remaining liquid phase portion from the outlet stream to produce a recirculation stream thereby increasing a mass proportion of the steam portion in the outlet stream. The system also includes a recirculation line operable to recirculate the recirculation stream back to the inlet of the steam generator.

ABSTRACT

A method and system for generating steam from a feedwater stream including impurities is disclosed. The system includes a steam generator having an inlet for receiving the feedwater stream and an outlet for producing an outlet stream. The steam generator is operable to cause vaporization of feedwater to generate the outlet stream including a steam portion having a lesser mass proportion than a remaining liquid phase portion. The system also includes a feed apparatus operable to deliver the feedwater stream to the inlet of a steam generator at a sufficiently high flow rate to reduce scaling within the steam generator. The system further includes a separator operable to separate at least a portion of the remaining liquid phase portion from the outlet stream to produce a recirculation stream thereby increasing a mass proportion of the steam portion in the outlet stream. The system also includes a recirculation line operable to recirculate the recirculation stream back to the inlet of the steam generator.

METHOD AND SYSTEM FOR GENERATING STEAM FROM A FEEDWATER STREAM INCLUDING IMPURITIES

BACKGROUND

1. Field

This disclosure relates generally to generating steam and more particularly to generating steam from a feedwater stream including impurities.

2. Description of Related Art

Steam assisted gravity drainage (SAGD) hydrocarbon recovery operations usually require that a stream of high steam quality be delivered to the wellhead, typically at or near 100 % steam quality.

Steam generation systems are used in hydrocarbon recovery operations to produce steam from produced water that may contain significant impurities. A typical steam generation system requires a treated and produced boiler feedwater. The steam generator typically produces an 80 % quality steam that is then sent to a steam separator to further improve steam quality to near 100 %.

Water produced from a hydrocarbon production facility, referred to as produced water or production water, may be treated and recycled for use in steam generation. Recycling of produced water typically requires overall removal of suspended solids, dissolved solids and of scale-forming chemicals, among other ions and chemical compounds that affect the operation of steam generating systems. Conventional processes are both complex and expensive when handling the specific chemistry of produced water and other oil and gas effluents.

The produced water is generally treated prior to being fed to the steam generator. In some instances, treatment stages may include emulsion treatment, deoiling, and water treatment, as shown in Figure **1**. Typically, the water treatment system may include a warm lime softener,

softener filters, a strong acid cation exchange unit, a weak acid cation exchange unit, and other equipment such as pumps and tanks. A conventional water treatment system may take up over 40 % of the total footprint of a typical central processing facility.

There remains a need for improved methods and systems for generating steam, particularly steam generation using a once-through steam generator (OTSG).

SUMMARY

In accordance with one disclosed aspect there is provided a method for generating steam from a feedwater stream including impurities. The method involves operating a steam generator to cause vaporization of feedwater to generate an outlet stream including a steam portion having a lesser mass proportion than a remaining liquid phase portion and delivering the feedwater stream to an inlet of the steam generator at a sufficiently high flow rate to reduce scaling within the steam generator. The method also involves separating at least a portion of the remaining liquid phase portion from the outlet stream to produce a recirculation stream thereby increasing a mass proportion of the steam portion in the outlet stream, and recirculating the recirculation stream through the steam generator.

Delivering the feedwater stream at a sufficiently high flow rate may involve delivering the feedwater stream at a flow rate that causes a substantial portion of impurities to remain in solution in the remaining liquid phase portion thus reducing scaling within the steam generator.

The method may involve removing and discharging a portion of the recirculation stream.

Recirculating may involve operating a pump to deliver the recirculation stream back to the inlet of the steam generator.

Recirculating may involve cooling the recirculation stream and delivering the recirculation stream back to a feedwater reservoir from which the feedwater stream may be delivered to the inlet of the steam generator.

The steam generator may include a radiant section disposed to receive a radiant heat flux from a burner and a convective section disposed to receive a residual heat flux from the radiant section, and the feedwater stream received at the inlet of the steam generator may flow through a first tubing section disposed within the convective section and then through a second tubing section disposed within the radiant section, and the outlet stream may be generated at an outlet of the second tubing section.

Recirculating may involve recirculating the recirculation stream back to an inlet of the second tubing section.

Separating may involve delivering the outlet stream to an inlet of a steam separator, delivering the feedwater stream flowing through the first tubing section from an outlet of the first tubing section to a feedwater inlet of the steam separator, and drawing a recirculation stream from a recirculating stream outlet of the steam separator to produce the recirculation stream.

Operating the steam generator may involve delivering a heat flux to the steam generator to cause vaporization of the feedwater and may further involve controlling the heat flux and a flow rate of the feedwater stream delivered to the inlet to maintain a sufficient kinetic energy in the feedwater stream.

The steam portion may have a mass proportion of between about 10 % and about 50 % of the outlet stream prior to separating.

The steam portion may have a mass proportion of between about 20 % and about 40 % of the outlet stream prior to separating.

The method may involve treating the recirculation stream to increase a pH of the recirculation stream within a pH range of about 8.5 to about 12.7.

Delivering the feedwater stream may involve delivering a feedwater stream blended with an additive including at least one of a chemical operable to inhibit scale formation from hardness and silica in the feedwater, an additive operable to provide for pH adjustment of the feedwater stream, a chemical chelant for reducing scale deposition, a dispersant polymer for reducing scale deposition, a sulfite for preventing corrosion, and an amine for preventing corrosion.

Operating the steam generator may involve generating a heat flux and may further involve causing vaporization of the feedwater by one of coupling the heat flux directly into the feedwater, coupling the heat flux through a wall of a tube carrying the feedwater, and coupling the heat flux into a heat transfer fluid, which is in thermal communication with the feedwater.

The feedwater stream may include a de-oiled water stream produced in a hydrocarbon recovery operation.

Operating the steam generator may involve operating a first steam generator for a first period of time and may further involve taking the first steam generator offline for maintenance to remove scale accumulation generated by operation over the first period of time, and diverting the feedwater stream to a second steam generator operable to cause vaporization of the feedwater for generating steam during a second period of time.

Separating may involve separating a sufficient portion of the remaining liquid phase portion from the outlet stream to increase a mass proportion of the steam portion in the outlet stream following separating to at or above 80 %.

The method may involve processing the recirculation stream to remove precipitated impurities.

In accordance with another disclosed aspect there is provided a system for generating steam from a feedwater stream including impurities. The system includes a steam generator having an inlet for receiving the feedwater stream and an outlet for producing an outlet stream, the steam generator being operable to cause vaporization of the feedwater to generate the outlet stream including a steam portion having a lesser mass proportion than a remaining liquid phase portion. The system also includes a feed apparatus operable to deliver the feedwater stream to the inlet of the steam generator at a sufficiently high flow rate to reduce scaling within the steam generator. The system further includes a separator operable to separate at least a portion of the remaining liquid phase portion from the outlet stream to produce a recirculation stream thereby increasing a mass proportion of the steam portion in the outlet stream, and a recirculation line operable to recirculate the recirculation stream back to the inlet of the steam generator.

The system may include a discharge line operable to discharge a portion of the recirculation stream from the system.

The recirculation line may be in fluid communication with the inlet of the steam generator.

The recirculation line may be in fluid communication with an inlet of the feed apparatus and may further include a cooler disposed within the recirculation line for cooling the recirculation stream.

The system may include a filter for processing the recirculation stream to remove precipitated impurities.

The system may include a filter disposed to filter the feedwater stream provided to the inlet of the steam generator.

The steam generator may include a radiant section disposed to receive a radiant heat flux from a burner, and a convective section disposed to receive a residual heat flux from the radiant section, a first tubing section disposed within the convective section, a second tubing section disposed within the radiant section, and the feedwater stream received at the inlet of the steam generator may flow through the first tubing section and then through the second tubing section, and the outlet stream may be generated at an outlet of the second tubing section.

The second tubing section may include an inlet and the recirculation line may recirculate the recirculation stream back to the inlet of the second tubing section.

The separator may include an inlet for receiving the outlet stream and a feedwater inlet in fluid communication with an outlet of the first tubing section for receiving the feedwater stream flowing through the first tubing section and the separator may further include a recirculating stream outlet for producing the recirculation stream.

Other aspects and features will become apparent to those ordinarily skilled in the art upon review of the following description of specific disclosed embodiments in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate disclosed embodiments,

Figure **1** is a schematic illustrating a prior art process for treating produced water for steam generation;

Figure **2** is a schematic illustrative of a disclosed process for treating produced water and generating low steam quality;

Figure **3** is a schematic view of a system for generating steam in accordance with a first disclosed embodiment;

Figure **4** is a schematic view of an alternative feed apparatus for use in the system shown in Figure **3**;

Figure **5** is a schematic view of another alternative feed apparatus for use in the system shown in Figure **3**; and

Figure **6** is a schematic view of a system for generating steam in accordance with another disclosed embodiment; and

Figure **7** is a schematic view of a system for generating steam in accordance with a further disclosed embodiment.

DETAILED DESCRIPTION

In the current economic climate, with low oil prices, there is a need to lower the cost of hydrocarbon production. More stringent environmental regulations on carbon emissions and waste streams further underscore the need for new technologies that will increase productivity without significantly impacting the bottom line, and reduce the facility's operating costs by simplifying infrastructure, decreasing pipe network, increasing modularization and/or shortening construction cycles. One such technology is a system for generating steam from a feedwater stream including impurities disclosed below. Unlike conventional central processing facilities, such as that shown in Figure **1**, the disclosed system eliminates the need for water treatment following the step of deoiling of the produced water from a hydrocarbon recovery operation. Conventional treated and produced boiler feedwater typically contains a silica content below about 50 mg/L (measured as SiO_2) and a total hardness below about 0.5 mg/L (measured as $CaCO_3$).

The disclosed system herein is based on the inventors' recognition that it is possible to generate steam for use in thermal oil recovery operations (for example SAGD) from produced water that has gone through a deoiling process, without further water treatment as shown schematically in Figure **2**. The produced boiler feedwater of the present invention may have a silica content of greater than about 150 mg/L and a total hardness of greater than about 10 mg/L. The impurity level in the produced boiler feedwater is thus orders of magnitude greater than what is traditionally considered feasible by industry and boiler manufacturers. This disclosed steam generation system would result in a significant environmental benefit in the ability to reduce the facility's footprint by up to 40 %, reduce waste disposal, and may result in a decrease in emissions.

Referring to Figure **3**, a system for generating steam from a feedwater stream including impurities is shown generally at **100**. The system **100** includes a steam generator **102** having an inlet **104** for receiving a feedwater stream and an outlet **106**. The steam generator **102** is operable to cause vaporization of feedwater to generate an outlet stream at the outlet **106**. The outlet stream includes a steam portion having a lesser mass proportion than a remaining liquid phase portion. In one embodiment the steam portion of the outlet stream is between about 10 % and about 50 % of the outlet stream by mass (i.e. a steam quality of between about 10 % and about 50 %). In other embodiments the steam portion of the outlet stream may be between about 20 % and about 40 % of the outlet stream by mass. The stream produced at the outlet **106** is thus a wet steam stream having a low steam quality.

In the embodiment shown in Figure **3**, the steam generator **102** includes a tubing circuit **142** in fluid communication with the inlet **104**. The tubing circuit **142** is housed within a chamber having a radiant section **150** and a convective section **152**. The tubing circuit **142** includes a plurality of tubing bends providing a folded tubing circuit extending through the chambers between the inlet **104** and the outlet **106**. The tubing circuit **142** includes a first tubing section **144** within the convective section **152** and a second tubing section **146** within the radiant section **150**. An outlet **158** of the first tubing section **144** is coupled to an inlet **160** of the second tubing section **146**. The steam generator **102** may be fired using a burner **154** that operates through combustion of a fuel gas received at a fuel inlet **136** and air received at an air inlet **138**.

The heat delivered to the radiant section **150** thus first heats the second tubing section **146** and is then delivered to the convective section **152** for heating the first tubing section **144** and is discharged through a flue **156**. The feedwater flowing through the tubing circuit **142** thus receives a higher heat flux in the tubing section **146** within the radiant section **150** than in the tubing section **144** in the convective section **152.** The heat delivered to the radiant and convective sections **150** and **152** delivers a heat flux through metal walls of the tubing circuit **142** to the feedwater stream to generate steam by causing evaporation of feedwater within the tubing circuit. In other embodiments where the tubing circuit includes multiple parallel tubing circuits, the tubing circuits may be housed in a common chamber and a single heat source may deliver a heat flux to each of the tubing circuits.

The system **100** also includes a feed apparatus **108** operable to deliver the feedwater stream to the inlet of the steam generator **102**. In this embodiment the feed apparatus **108** includes a feedwater holding tank **110**, a pump **112**, and a mixer **126**. The pump **112** is operable to draw feedwater from the feedwater holding tank **110** and deliver feedwater through the mixer **126** to the inlet **104** at a sufficiently high flow rate to reduce scaling within the steam generator. In other embodiments the pump **112** may be omitted where the holding tank **110** is configured as a pressure vessel or the feedwater is supplied directly on a feedwater line from another process. In prior steam generation systems, feedwater may be delivered at a flow rate of about 2 – 3 m/s and typically less than about 4 m/s. Flow rates exceeding about 4 m/s would generally be avoided to prevent an excessive pressure drop in the convective section of the steam generator. In contrast, for the steam generator **102** shown in Figure **3**, the flow rate through the first tubing section **144** may be greater than 4 m/s, and in some embodiments up to about 5 m/s. In the second tubing section **146** within the radiant section **150**, flow rates are generally higher.

The system **100** also includes a steam separator **114** having an inlet **116**, a steam outlet **118**, and a recirculation stream outlet **120**. The steam separator **114** is operable to separate at least a portion of a remaining liquid phase portion from the outlet stream to produce a recirculation stream at the recirculation stream outlet **120**. Separation of liquid phase portions of the outlet stream increases a mass proportion of the steam portion in the outlet stream at the steam outlet **118** to have an increased steam proportion by mass. For example, in one embodiment where the steam quality at the outlet **106** of the steam generator **102** is less than 50 %, the steam quality at the steam outlet **118** of the steam separator **114** may be between about 80 % and about 100 %.

The system **100** further includes a recirculation line **122** in fluid communication with the inlet **104** of the steam generator **102**. The recirculation line **122** is thus operable to recirculate the recirculation stream from the recirculation stream outlet **120** back to the inlet **104**. In the embodiment shown the recirculation line **122** includes a pump **124**, which operates to deliver the recirculation stream back to the inlet **104** of the steam generator **102** via the mixer **126**. In one embodiment the mixer may be implemented using a mixing valve that controls the respective proportions of the feedwater and recirculation streams delivered to the inlet **104**. In other embodiments the mixer may be implemented using a Tee-junction, eductor, or other suitable equipment. The recirculation stream thus mixes with the feedwater stream and is delivered to the inlet **104**. The mixing of the recirculation stream at elevated temperature and the feedwater stream thus provides a heated stream at the inlet **104**. The recirculation stream would typically have a temperature above 100 °C, and possibly a temperature in a range of about 220 °C to about 270 °C. In general the temperature of the recirculation stream would be below the saturation temperature at the mixing pressure.

In other embodiments the pump **124** may be omitted and the recirculation line **122** may deliver the recirculation stream back to an inlet **128** of the feedwater holding tank **110**. In this embodiment the recirculation line **122** may include a cooler **130** disposed within the recirculation line for cooling the recirculation stream prior to mixing with the feedwater in the feedwater holding tank **110**.

In the embodiment shown in Figure **3**, the steam separator **114** also includes a discharge outlet **132** in communication with a discharge line **134** for discharging a portion of the recirculation stream from the system **100**. The discharged portion would include entrained impurities and may be further treated before reuse as a feedwater or use in another process. In one embodiment the discharged portion at the discharge outlet **132** may be less than about 10 % of the recirculation stream.

Operation of the system **100** differs from existing steam generators in that the steam generator **102** operates at a low steam quality, which in one embodiment may be a steam quality of less than 50 %. The system **100** relies on the steam separator **114** to upgrade the steam quality to between about 80 % and about 100 %. In order to maintain steam production at or near the production level that would be provided by conventional steam generators, the feedwater fluid flow rate delivered to the inlet **104** of the steam generator **102** is increased to produce a similar quantity of steam. The high fluid flow rate within the steam generator **102** also causes increased kinetic energy within the fluid flow, which is believed to reduce the propensity for impurities in the feedwater to cause scaling within the steam generator **102**. It is believed that the stream kinetic energy in a steam generator should be maintained within a range of values bounded by a minimum kinetic energy that still acts to reduce scale formation and a maximum kinetic energy above which it is expected that erosion of the tubing may occur. Examples of empirically determined bounds for kinetic energy would be a minimum of about 15,000 $lbft^{-1}s^{-2}$ and a maximum of about 30,000 $lbft^{-1}s^{-2}$. Increasing the flow rate through the steam generator **102** lowers produced steam quality with a corresponding decrease in the density of the stream. In conjunction, the firing rate of the steam generator **102** may also be reduced to reduce a heat flux produced for heating the feedwater within the steam generator, which also provides a control for reducing steam quality. The operating parameters of flow rate, firing rate, and steam quality are thus selected to operate the steam generator **102** within a desired kinetic energy range and for a targeted steam production at the steam outlet **118**. When the flow rate at which the feedwater stream is delivered is selected as described above, this is believed to cause a substantial portion of impurities to remain in solution in the liquid phase portion thus reducing scaling within the steam generator **102**. In one embodiment the proportion of impurities remaining in solution in the liquid phase may be between about 50 % and about 90 %.

It is generally desirable to minimize the liquid portion produced at the outlet **106** of the steam generator **102** so that the liquid phase portion recovered in the steam separator **114** is minimized. Typically the recovered liquid phase portion (commonly referred to as "blowdown") must be disposed of, treated, or used elsewhere in operations. For the system **100** disclosed herein, the low steam quality at the outlet **106** generates a significant blowdown, however most of this stream is diverted into the recirculation stream and only the discharge portion at the discharge outlet **132** need be disposed of or treated.

In one embodiment the feedwater stream is received at the inlet **128** and held in the feedwater holding tank **110**. The pump **112** draws feedwater from an outlet **140** of the feedwater holding tank **110** and delivers the feedwater stream to the inlet **104** of the steam generator **102**. The feedwater may be produced water from a previous hydrocarbon recovery operation, in which case the water will generally require treatment to remove hydrocarbon products providing a "de-oiled" feedwater stream. An oil content of between about 0.1 and 10 mg/L may generally be acceptable in the de-oiled feedwater. Other impurities in the feedwater may include calcium, magnesium, iron, silica, hydrogen sulphide, chloride, oxygen, and other dissolved solids and/or gasses. The feedwater stream may have a pH in the range of 7 – 10.

By way of example, a feedwater stream at a flow rate of about 100 m^3/hour cold water equivalent (CWE) may be delivered to the inlet **104** and the steam generator **102** may be operated to produce a steam quality of about 25 % at the outlet **106**. CWE is a term used to express an amount of steam (water in a gas or vapor phase) based on the amount of water that would be required to produce it. Thus, the liquid portion of the outlet stream at the outlet **106** will have a flow rate of about 75 m^3/hour. In one embodiment about 8 % of this stream is discharged at the discharge outlet **132**, leaving a recirculation stream having a flow rate of about 69 m^3/hour. An additional 31 m^3/hour of feedwater from the holding tank **110** will thus be supplied through the pump **112** and mixer **126** to make up the 100 m^3/hour flow rate at the inlet **104**. While the recirculated stream will likely have an increased level of impurities in solution, the addition of 31 m^3/hour of feedwater from the holding tank **110** dilutes the stream at the inlet **104**. Furthermore the optional removal of a discharge stream having a flow rate of about 6 m^3/hour at the discharge outlet **132** removes some of the feedwater having increased impurity levels. The flow rates in the preceding example are only provided for illustrative purposes and may be different in a commercial operation depending on the configuration and size of steam generator implemented.

Referring to Figure **4**, an alternative feed apparatus embodiment is shown at **200**. The feed apparatus **200** includes the feedwater holding tank **110** and pump **112** shown in Figure **3** and further includes a mixer **202**. The feedwater stream from the outlet **140** of the feedwater holding tank **110** flows through the mixer **202** to the inlet **104** of the steam generator **102** (not shown in Figure **4**). The recirculation line **122** carries the recirculation stream through the mixer **202** to the inlet **104**. The mixer **202** includes an additional inlet for receiving additive from a feeder **206**. The additives may include various chemical additives as described below.

In one embodiment an additive such as sodium hydroxide (NaOH) or lime may be added to adjust the pH level of the feedwater to maintain silica in solution. It is believed by the inventors that a pH in the range of about 8.5 to about 12.7 should be sufficient to prevent silica from precipitating. In some embodiments, a chelant may be added to inhibit scale formation from hardness and silica and to prevent scale deposition by keeping magnesium and calcium in solution. For example an ethylenediaminetetraacetic acid (EDTA) chelant may be added to the feedwater, for example in the form of an aqueous EDTA solution. In other embodiments a dispersant polymer may be added, which keeps magnesium and calcium in solution and helps prevent scale deposition on tubing walls and/or inhibits crystal growth. In some embodiments sulfite and/or amine may be added to reduce corrosion. Suitable additives should be formulated for operation at high temperatures (for example temperatures over 300 °C for more than 3 to 4 minutes).

Referring to Figure **5**, another alternative feed apparatus embodiment is shown at **300**. The feed apparatus **300** includes the feedwater holding tank **110**, pump **112**, and mixer **126**, shown in Figure **3** and further includes a filter **302** disposed to filter the feedwater stream provided to the inlet **104**. The filter **302** is operable to process the feedwater stream to remove precipitated impurities. The pumps **112** and **124** drive the feedwater and recirculation stream, respectively, through the mixer **126** to the filter **302**, which filters out precipitated impurities and provides the filtered feedwater stream to the inlet **104** of the steam generator **102** (not shown). In some embodiments a filter **304** may also be disposed in the recirculation line **122** for filtering the recirculation stream. The filter **304** may be implemented in addition to the filter **302** or instead of the filter **302**, and is operable to process the recirculation stream to remove precipitated impurities.

Additionally, in some embodiments a filter **306** may be disposed in the discharge line **134** for filtering the discharge or "blowdown" stream. In general, the discharge stream would be expected to have high levels of contaminants including, for example, hardness and silica. As the temperature of the discharge stream is reduced, the solubility of the contaminants may also be reduced causing additional challenges related to disposal of these contaminants. The filter **306** provides for further treatment of the discharge stream. In some embodiments the filter **306** may be implemented through alternative filtration processes such as evaporation, crystallization or chemical treatment, or other treatment process that removes precipitated impurities.

The steam generator **102** may be implemented using different steam generator configurations. In a once-through steam generator (OTSG) feedwater flows through a metal tubing circuit between an inlet and steam outlet and a burner generates a heat flux which is coupled through the wall of the metal tubing into the feedwater. The feedwater may be forced through the tubing circuit by a pump (such as shown at **112** in Figure **3**). The OTSG may further include an economizer section for preheating the feedwater stream to a temperature near or at the boiling point of the feedwater.

In other embodiments the steam generator **102** may be implemented using a heat recovery steam generator (HRSG), which includes an inlet for receiving a heated gaseous flow discharged as an exhaust gas produced through conversion of a primary fuel source to provide energy for other processes, such as generation of electricity for example. The HRSG includes an economizer section for heating the feedwater in a tubing circuit and an evaporator section for causing evaporation of the feedwater stream to generate an outlet stream of high steam quality. In other embodiments, the HRSG may include other sections, including for example more than one economizer section and/or more than one evaporator section. In general, SAGD operations may use several OTSGs and/or HRSGs to generate adequate volumes of steam for hydrocarbon recovery operations.

In operation it is expected that the steam generator **102** may still be subjected to scaling due to some precipitation of scaling products from the feedwater. The scale may be accumulated over time and require removal. For example, the tubing circuit of a once-through steam generator may be "pigged" to remove scaling by passing a pigging device through the tubing circuit. In one embodiment the system **100** shown in Figure **3** may include a second steam generator that enables maintenance on the first steam generator while the second steam generator is operated to generate steam. The first steam generator may be taken offline for maintenance to remove scale accumulation generated by operation over the first period of time and the feedwater stream diverted to the second steam generator for generating steam during a second period of time. The additional capital cost and footprint occupied by the redundant steam generator may be offset by the increased up-time for the overall system. It is expected that pigging of the tubing circuit may be required about every 1 – 6 months. In some embodiments, where warranted by the scale of operations, more than two steam generators may be used in rotation to provide a desired steam production and overall system up-time.

Referring back to Figure **3**, in one embodiment feedwater entering the mixer **126** from the feedwater holding tank **110** may be at about 190 °C and the recirculation line **122** may deliver the recirculation stream at a temperature of about 310 °C. This may result in a feedwater temperature between 190 °C and 310 °C, for example, of about 250 °C at the inlet **104** and through at least a portion of the tubing section **144**. A resulting flue gas discharge temperature within the flue **156** may thus also be in the region of about 250 °C. Referring to Figure **6**, an alternative embodiment of a steam generation system is shown generally at **600**. In this embodiment the recirculation stream is recirculated from the recirculation stream outlet **120** of the steam separator **114**, via the pump **124**, to the inlet **160** of the second tubing section **146** within the radiant section **150**. In embodiments where the temperature of the recirculation stream is about 310 °C, the relatively hot recirculation stream is thus combined with the stream that is heated while flowing through the first tubing section **144** in the convective section **152**. As disclosed above, the stream at the inlet **104** may have a temperature of about 190 °C and is pre-heated by the residual heat remaining after the feedwater flowing through the second tubing section **146** has been heated in the radiant section **150**. The feedwater flowing through the first tubing section **144** in the convective section **152** will thus be at a lower temperature than in the embodiment shown in Figure **3**, and the temperature of the flue gasses in the flue **156** will remain at a lower temperature (i.e. closer to 190 °C). Discharging flue gasses at a lower temperature corresponds to improved energy efficiency for the system **600**.

Referring to Figure **7**, a further embodiment is shown generally at **700**. In this embodiment, a steam separator **702** is disposed stacked on top of the steam generator **102**, which reduces the physical footprint of the steam generation system **700**. The steam separator **702** has a feedwater inlet **704** for receiving the feedwater stream from the outlet **158** of the first tubing section **144**, which may be at a temperature of about 190 °C after passing though the convective section **152**. The steam separator **702** also includes an inlet **706** and the stream discharged from the outlet **106** of the second tubing section **146** is recirculated back to the inlet **706** as a recirculation stream. This recirculation stream will be at a higher temperature than the stream received at the inlet **704**. An optional baffle **708** within the steam separator **702** may be used to provide for separation between the lower temperature stream received at the inlet **704** and the higher temperature recirculation stream received at the inlet **706**. The inlet **160** of the second tubing section **146** is fed via a pump **710** from a recirculating stream outlet **712** on the lower temperature side of the baffle **708**. Steam having an increased steam proportion by mass is provided at the steam outlet **714**. The steam separator **702** also includes a discharge outlet **716** for discharging a stream including entrained impurities via a discharge line **718**. The baffle **708** may help prevent the lower temperature stream received at the inlet **704** from bypassing the recirculating stream outlet **712** in favour of the discharge outlet **716**.

The steam generation system embodiment **700** operates at similar energy efficiency to the steam generation system **600** shown in Figure **6**, but reduces the physical space needed to accommodate the system.

While specific embodiments have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

What is claimed is:

1. A method for generating steam from a feedwater stream including impurities, the method comprising:

operating a steam generator to cause vaporization of feedwater to generate an outlet stream including a steam portion having a lesser mass proportion than a remaining liquid phase portion;

delivering the feedwater stream to an inlet of the steam generator at a sufficiently high flow rate to reduce scaling within the steam generator;

separating at least a portion of the remaining liquid phase portion from the outlet stream to produce a recirculation stream thereby increasing a mass proportion of the steam portion in the outlet stream; and

recirculating the recirculation stream through the steam generator.

2. The method of claim **1** wherein delivering the feedwater stream at a sufficiently high flow rate comprises delivering the feedwater stream at a flow rate that causes a substantial portion of impurities to remain in solution in the remaining liquid phase portion thus reducing scaling within the steam generator.

3. The method of claim **1** further comprising removing and discharging a portion of the recirculation stream.

4. The method of claim **1** wherein recirculating comprises operating a pump to deliver the recirculation stream back to the inlet of the steam generator.

5. The method of claim **1** wherein recirculating comprises:

cooling the recirculation stream and

delivering the recirculation stream back to a feedwater reservoir from which the feedwater stream is delivered to the inlet of the steam generator.

6. The method of claim **1** wherein the steam generator comprises a radiant section disposed to receive a radiant heat flux from a burner and a convective section disposed to receive a residual heat flux from the radiant section, and wherein the feedwater stream received at the inlet of the steam generator flows through a first tubing section disposed within the convective section and then through a second tubing section disposed within the radiant section, and wherein the outlet stream is generated at an outlet of the second tubing section.

7. The method of claim **6** wherein recirculating comprises recirculating the recirculation stream back to an inlet of the second tubing section.

8. The method of claim **7** wherein separating comprises:

delivering the outlet stream to an inlet of a steam separator;

delivering the feedwater stream flowing through the first tubing section from an outlet of the first tubing section to a feedwater inlet of the steam separator; and

drawing a recirculation stream from a recirculating stream outlet of the steam separator to produce the recirculation stream.

9. The method of claim **1** wherein operating the steam generator comprises delivering a heat flux to the steam generator to cause vaporization of the feedwater and further comprising controlling the heat flux and a flow rate of the feedwater stream delivered to the inlet to maintain a sufficient kinetic energy in the feedwater stream.

10. The method of claim **1** wherein the steam portion has a mass proportion of between about 10 % and about 50 % of the outlet stream prior to separating.

11. The method of claim **1** wherein the steam portion has a mass proportion of between about 20 % and about 40 % of the outlet stream prior to separating.

12. The method of claim **1** further comprising treating the recirculation stream to increase a pH of the recirculation stream within a pH range of about 8.5 to about 12.7.

13. The method of claim **1** wherein delivering the feedwater stream comprises delivering a feedwater stream blended with an additive comprising at least one of:

a chemical operable to inhibit scale formation from hardness and silica in the feedwater;

an additive operable to provide for pH adjustment of the feedwater stream;

a chemical chelant for reducing scale deposition;

a dispersant polymer for reducing scale deposition;

a sulfite for preventing corrosion; and

an amine for preventing corrosion.

14. The method of claim **1** wherein operating the steam generator comprises generating a heat flux and further comprising causing vaporization of the feedwater by one of:

coupling the heat flux directly into the feedwater;

coupling the heat flux through a wall of a tube carrying the feedwater; and

coupling the heat flux into a heat transfer fluid, which is in thermal communication with the feedwater.

15. The method of claim **1** wherein the feedwater stream comprises a de-oiled water stream produced in a hydrocarbon recovery operation.

16. The method of claim **15** wherein operating the steam generator comprises operating a first steam generator for a first period of time and further comprising:

taking the first steam generator offline for maintenance to remove scale accumulation generated by operation over the first period of time; and

diverting the feedwater stream to a second steam generator operable to cause vaporization of the feedwater for generating steam during a second period of time.

17. The method of claim **1** wherein separating comprises separating a sufficient portion of the remaining liquid phase portion from the outlet stream to increase a mass proportion of the steam portion in the outlet stream following separating to at or above 80 %.

18. The method of claim **1** further comprising processing the recirculation stream to remove precipitated impurities.

19. A system for generating steam from a feedwater stream including impurities, the system comprising:

a steam generator having an inlet for receiving the feedwater stream and an outlet for producing an outlet stream, the steam generator being operable to cause vaporization of the feedwater to generate the outlet stream including a steam portion having a lesser mass proportion than a remaining liquid phase portion;

a feed apparatus operable to deliver the feedwater stream to the inlet of the steam generator at a sufficiently high flow rate to reduce scaling within the steam generator;

a separator operable to separate at least a portion of the remaining liquid phase portion from the outlet stream to produce a recirculation stream thereby increasing a mass proportion of the steam portion in the outlet stream; and a recirculation line operable to recirculate the recirculation stream back to the inlet of the steam generator.

20. The system of claim **19** further comprising a discharge line operable to discharge a portion of the recirculation stream from the system.

21. The system of claim **19** wherein the recirculation line is in fluid communication with the inlet of the steam generator.

22. The system of claim **19** wherein the recirculation line is in fluid communication with an inlet of the feed apparatus and further comprising a cooler disposed within the recirculation line for cooling the recirculation stream.

23. The system of claim **19** further comprising a filter for processing the recirculation stream to remove precipitated impurities.

24. The system of claim **19** further comprising a filter disposed to filter the feedwater stream provided to the inlet of the steam generator.

25. The system of claim **19** wherein the steam generator comprises:

a radiant section disposed to receive a radiant heat flux from a burner; and

a convective section disposed to receive a residual heat flux from the radiant section;

a first tubing section disposed within the convective section;

a second tubing section disposed within the radiant section; and

wherein the feedwater stream received at the inlet of the steam generator flows through the first tubing section and then through the second tubing section, and wherein the outlet stream is generated at an outlet of the second tubing section.

26. The system of claim **25** wherein the second tubing section includes an inlet and wherein the recirculation line recirculates the recirculation stream back to the inlet of the second tubing section.

27. The system of claim **26** wherein the separator comprises an inlet for receiving the outlet stream and a feedwater inlet in fluid communication with an outlet of the first tubing section for receiving the feedwater stream flowing through the first tubing section and wherein the separator further comprises a recirculating stream outlet for producing the recirculation stream.

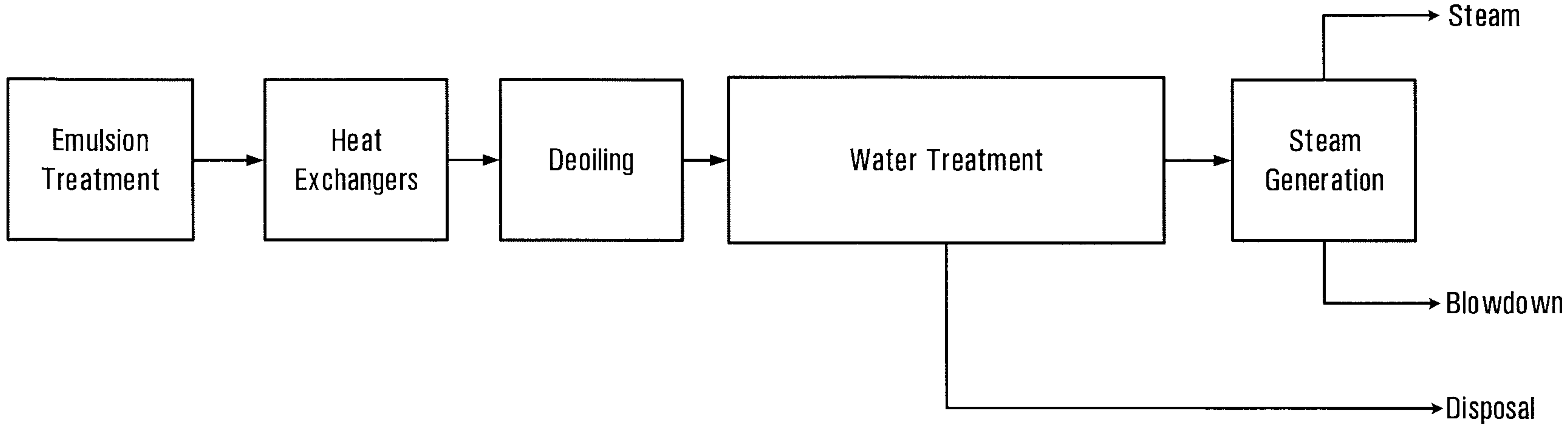


FIG. 1
Prior Art

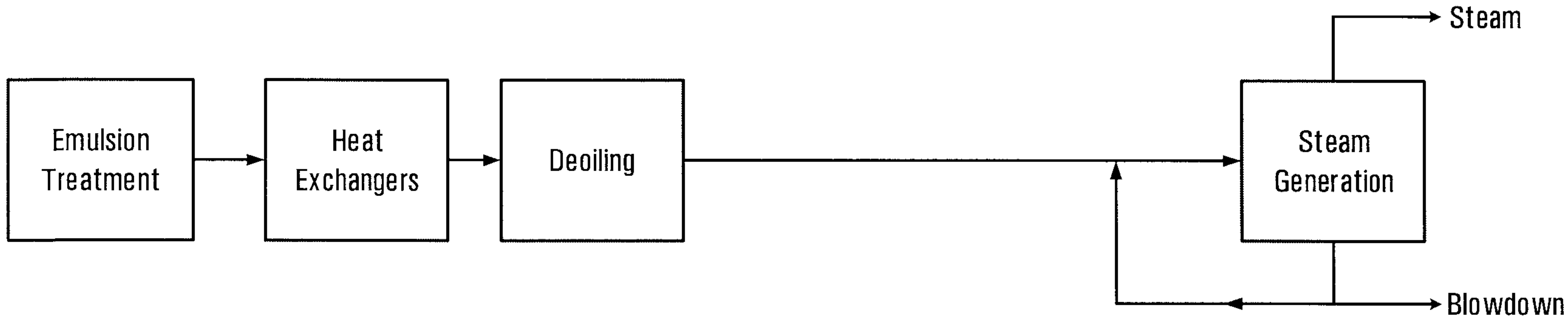


FIG. 2

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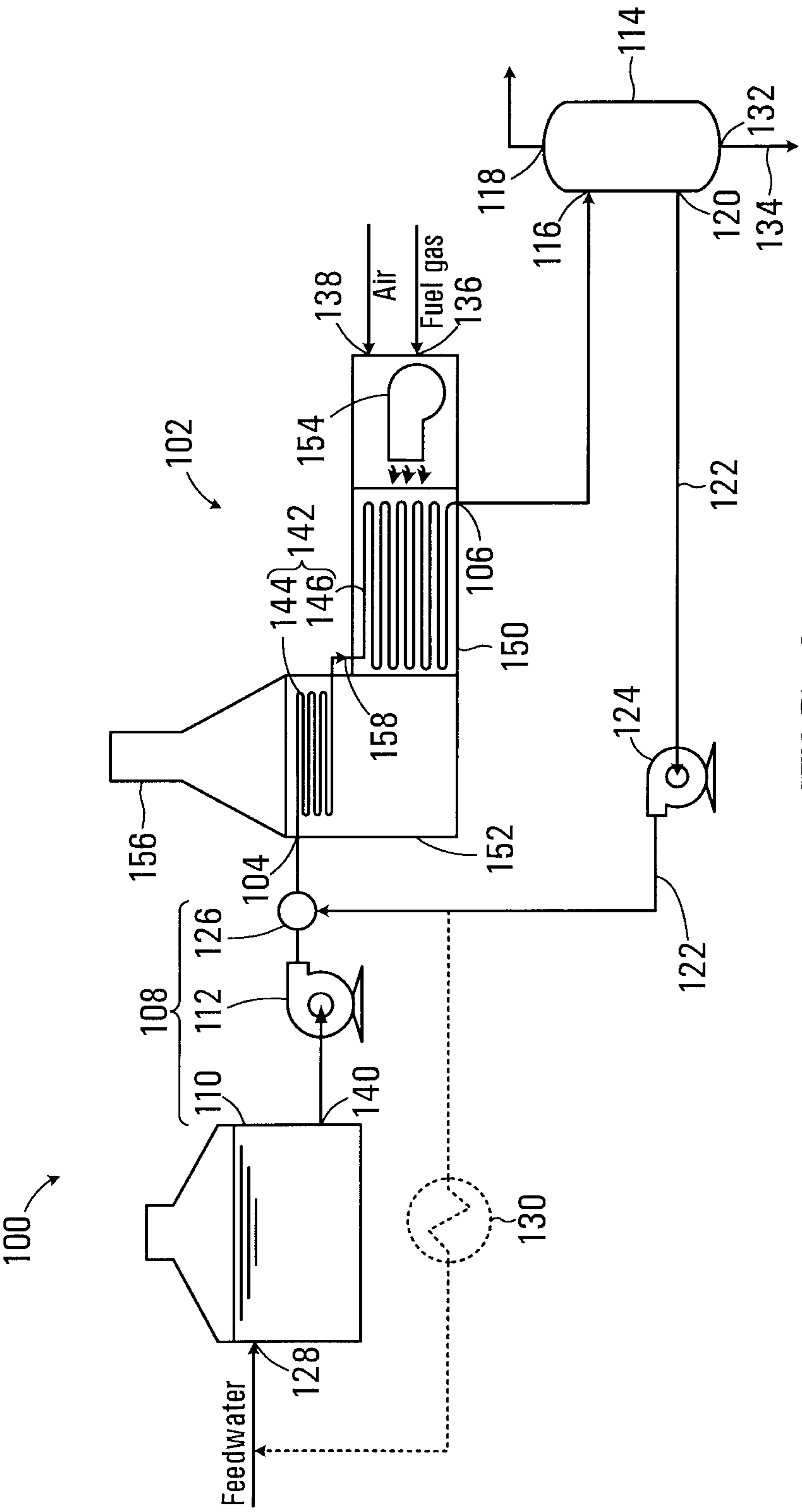
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Fuel gas
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FIG. 3

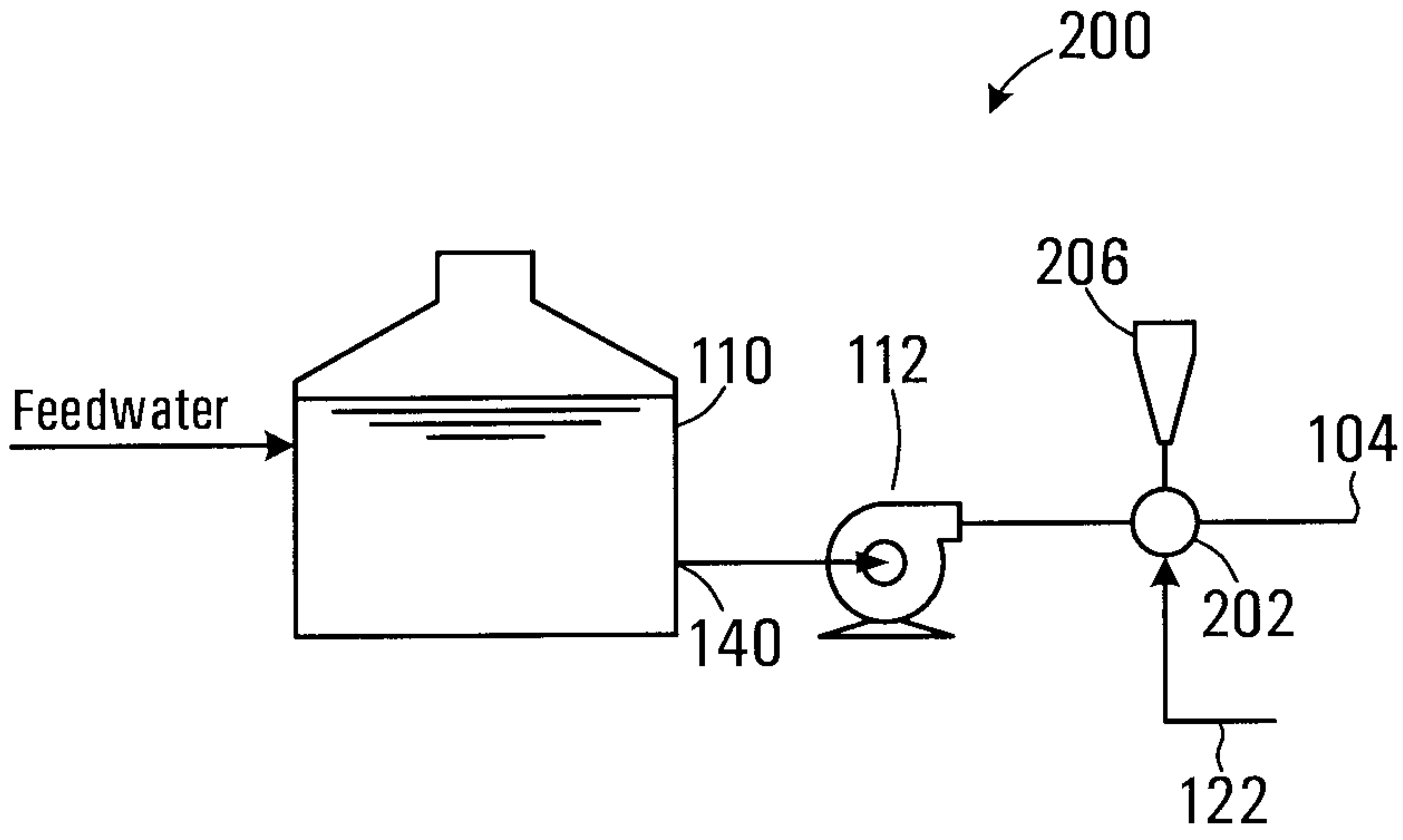
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FIG. 4

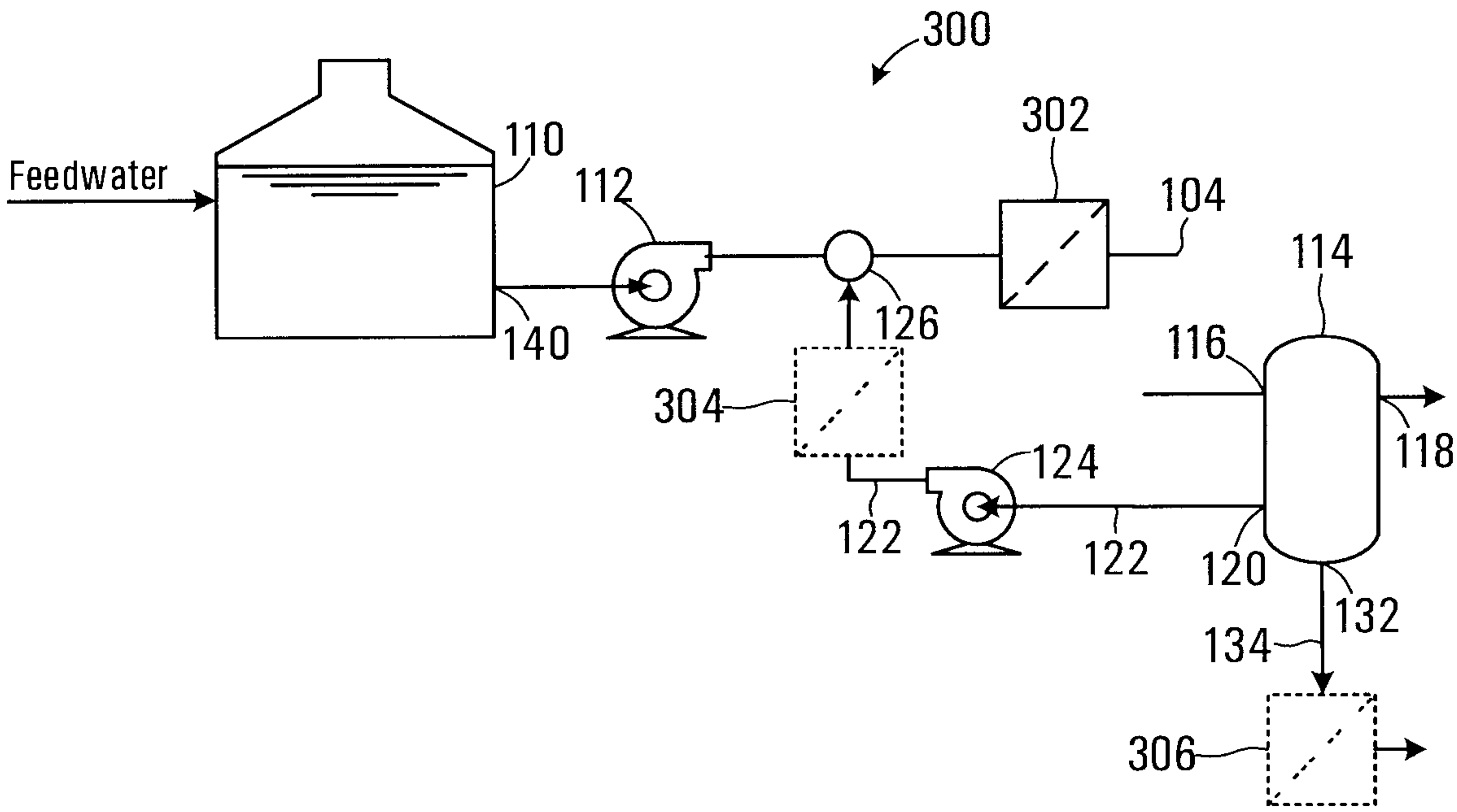
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FIG. 5

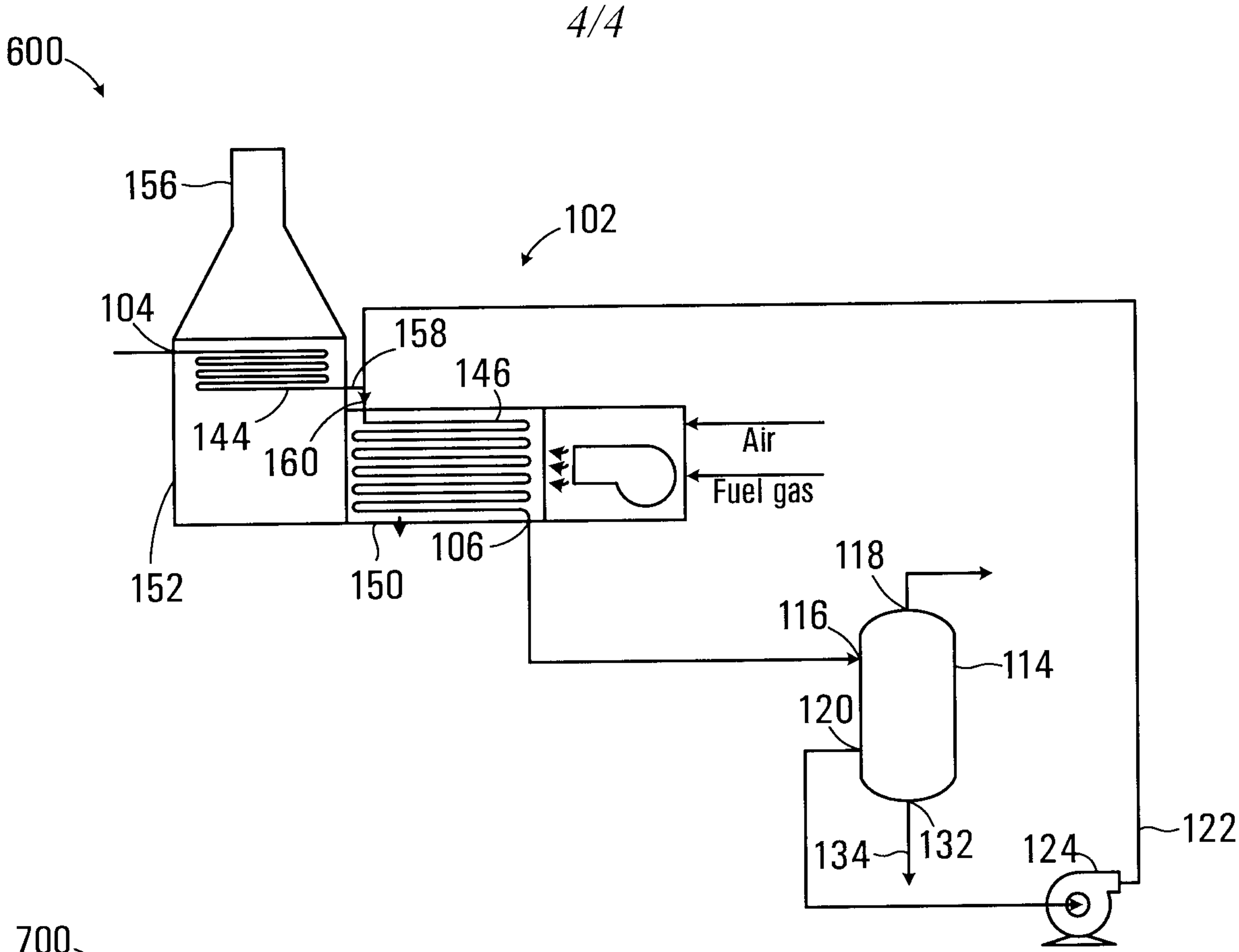
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FIG. 6

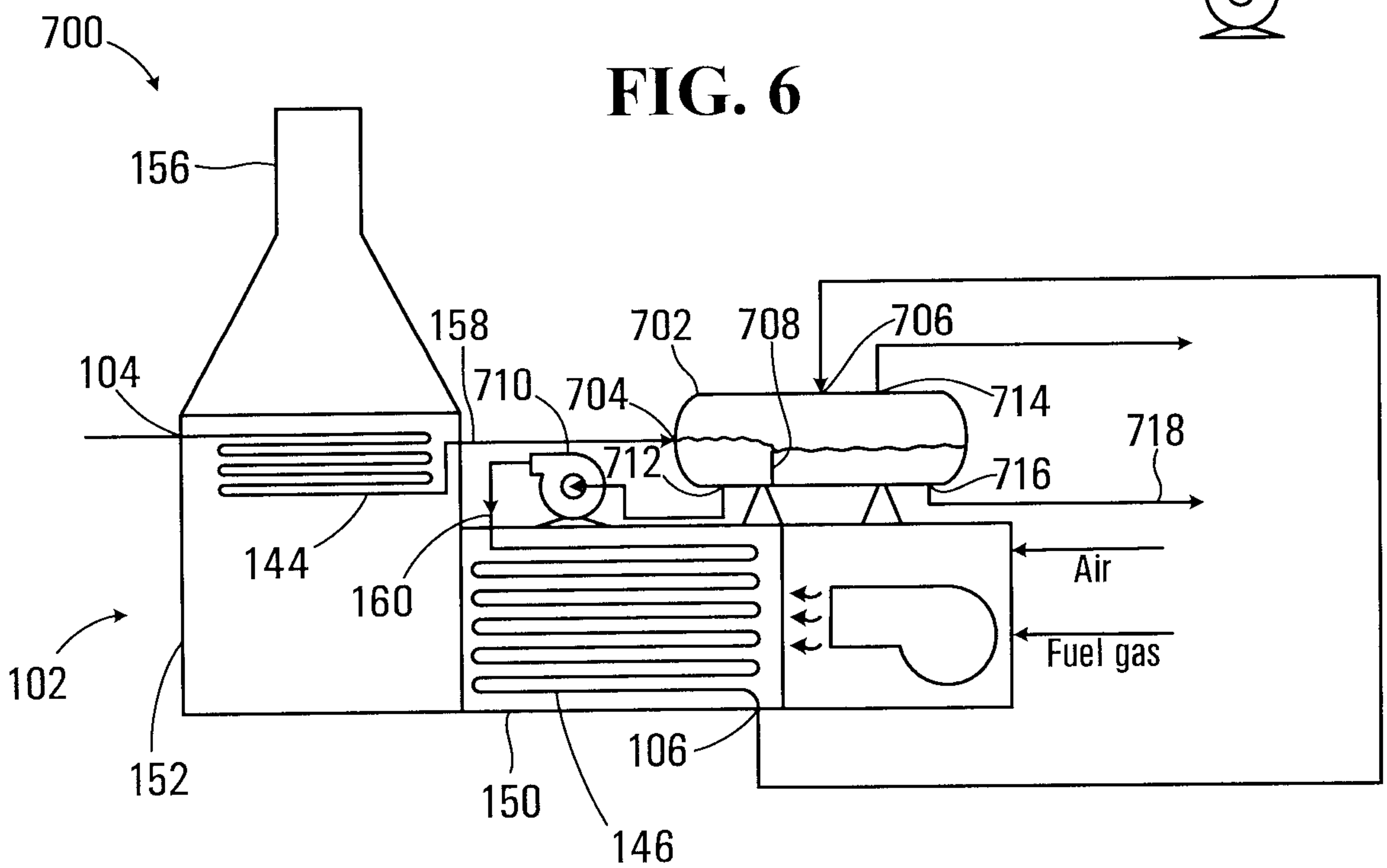
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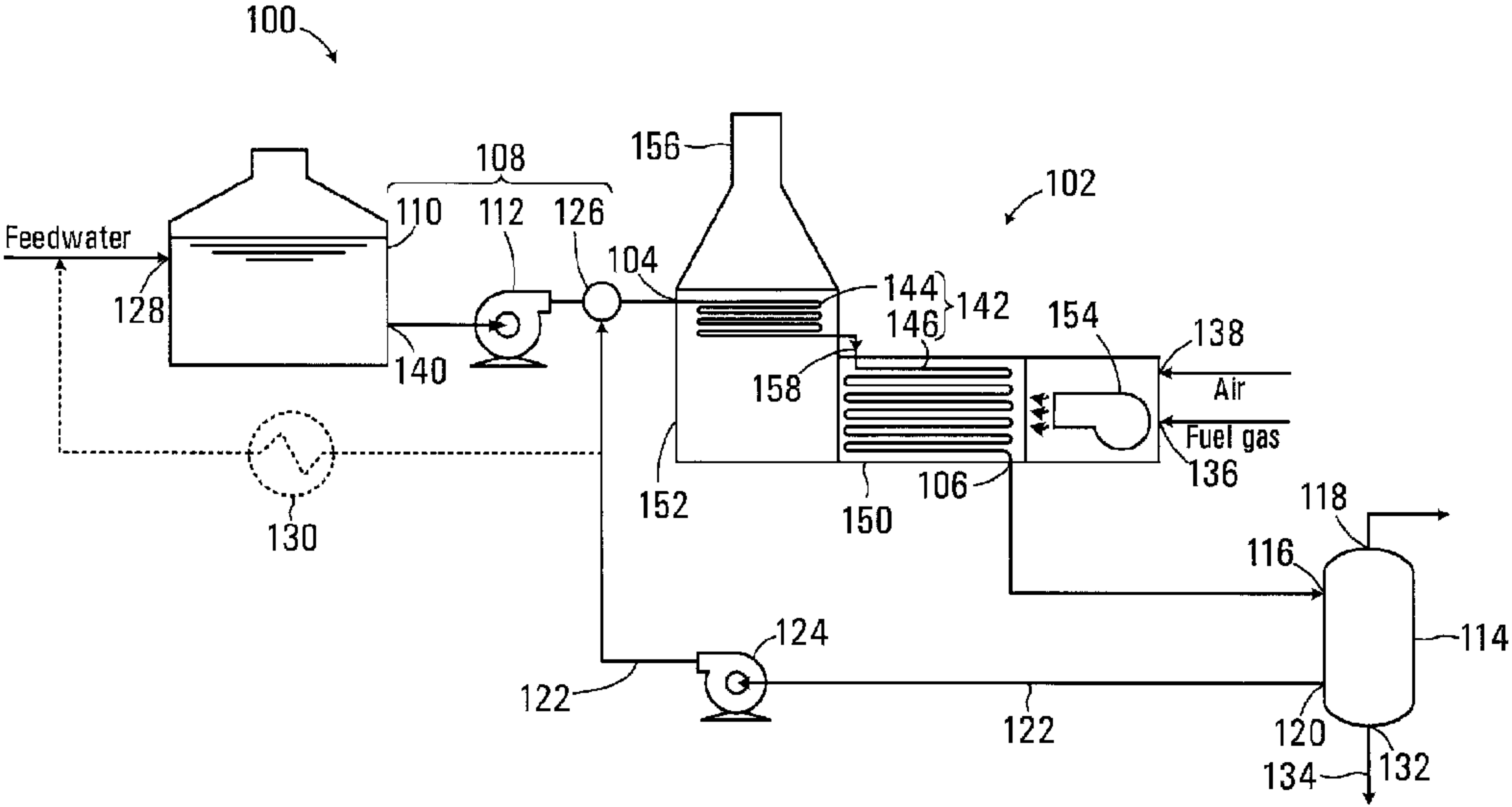
FIG. 7



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