United States Patent	12390767
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Benton; Charles et al.

Removing components of alcoholic solutions via forward osmosis and related systems

Abstract

Examples disclosed herein relate to methods and systems for controllably removing one or more solutes from a solution. Examples disclosed herein relate to methods and systems for removing water from alcoholic beverages.

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Appl. No.: **18/051450**

Filed: **October 31, 2022**

Prior Publication Data

Document Identifier	Publication Date
US 20230149853 A1	May. 18, 2023

Related U.S. Application Data

division parent-doc US 16473088 US 11541352 WO PCT/US2017/068345 20171222 child-doc US 18051450
us-provisional-application US 62438950 20161223

Publication Classification

Int. Cl.: **B01D61/00** (20060101); **B01D61/02** (20060101); **B01D61/36** (20060101); **B01D61/58** (20060101); **C12G3/08** (20060101); **C12H3/00** (20190101); **C12H3/02** (20190101); **C12H6/00** (20190101)

U.S. Cl.:

CPC **B01D61/0024** (20220801); **B01D61/025** (20130101); **B01D61/029** (20220801); **B01D61/362** (20130101); **B01D61/364** (20130101); **B01D61/58** (20130101); **C12G3/08** (20130101); **C12H3/00** (20190201); **C12H3/02** (20190201); **C12H6/00** (20190201); B01D2311/06 (20130101); B01D2311/08 (20130101); B01D2311/2521 (20220801); B01D2311/2669 (20130101); B01D2317/022 (20130101); B01D2317/025 (20130101); B01D2317/06 (20130101); B01D2317/08 (20130101)

Field of Classification Search

CPC: B01D (61/002); B01D (61/022); B01D (61/025); B01D (61/362); B01D (61/364); B01D (61/58); B01D (2311/06); B01D (2311/08); B01D (2311/25); B01D (2311/2669); B01D (2317/022); B01D (2317/025); B01D (2317/06); B01D (2317/08); C12C (11/11); C12G (3/08); C12H (3/00); C12H (3/02); C12H (3/04); C12H (6/00)

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION(S) (1) This application is a divisional application of U.S. application Ser. No. 16/473,088, filed Jun. 24, 2019, which is a 371 national phase filing of PCT Application No. PCT/US2017/068345, filed Dec. 22, 2017, which claims the benefit under 35 U.S.C. § 119 of the earlier filing date of U.S. Application No. 62/438,950, filed Dec. 23, 2016. The entire contents of the afore-mentioned priority application are hereby incorporated by reference in their entirety for any purpose.

BACKGROUND

(1) Existing techniques for dewatering alcoholic solutions include both thermal processes (e.g.,

distillation, evaporation), and hydrostatic pressure-driven membrane processes (e.g., reverse osmosis, nanofiltration, ultrafiltration). Thermal processes may be disadvantageous for concentration of alcoholic solutions because of high energy consumption, loss of volatile organic compounds (VOCs), and modification to protein structures important to flavor, aroma, and taste. Pressure driven membrane processes may be limited by poor retention of alcohol and VOCs, and hydrostatic pressure limits.

SUMMARY

(2) Methods for concentrating a solution are disclosed. An example method includes introducing a feed solution having at least one permeable solute into a first side of a forward osmosis system. The example method includes circulating a draw solution through a second side of the forward osmosis system in a countercurrent flow with respect to the feed solution, the draw solution having one or more solutes and a concentration of the at least one permeable solute that is lower than a concentration of the at least one permeable solute in the feed solution. The example method includes generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and higher at least one permeable solute concentration than the draw solution. The example method includes producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a lower water content and a concentration of the at least one permeable solute that is less than the concentration of the at least one permeable solute in the feed solution. The example method includes regenerating the draw solution from the diluted draw solution. The example method includes recirculating the draw solution that has been regenerated through the second side of the forward osmosis system

(3) Methods for concentrating an alcoholic solution via forward osmosis are disclosed. An example method includes introducing an alcoholic beverage into a first side of a forward osmosis system. The example method includes circulating a draw solution in a second side of the forward osmosis system in a countercurrent flow with respect to the alcoholic beverage, the draw solution having an alcohol concentration lower than the alcohol concentration in the alcoholic beverage. The example method includes generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and higher alcohol concentration than the draw solution. The example method includes producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content from the first side of the forward osmosis system. The example method includes regenerating the draw solution from the diluted draw solution. The example method includes producing a permeate stream from the diluted draw solution.

(4) Systems for concentrating a solution are disclosed. An example system includes a forward osmosis element including at least one selectively permeable forward osmosis membrane separating a first side of the forward osmosis element from a second side of the forward osmosis element. The example system includes a supply of a solution containing one or more permeable solutes fluidly coupled to the first side. The example system includes a supply of a draw solution operably coupled to the second side in a countercurrent flow with respect to the first side, the draw solution having a concentration of the one or more permeable solutes that is less than a concentration of the one or more permeable solutes in the solution and a total solutes concentration higher than a total solutes concentration of the solution. The example system includes at least one draw solution regenerating apparatus operably coupled to the second side and configured to receive output therefrom.

(5) Methods for maintaining an amount of one or more solutes in a solution while removing water therefrom are disclosed. The example method includes introducing a feed solution having at least one permeable solute into a first side of a forward osmosis system. The example method includes circulating a draw solution through a second side of the forward osmosis system, the draw solution having one or more solutes and a concentration of the at least one permeable solute that is greater

than a concentration of the at least one permeable solute in the feed solution. The example method includes generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and lower at least one permeable solute concentration than the draw solution. The example method includes producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a lower water content and a concentration of the at least one permeable solute that is higher than the concentration of the at least one permeable solute in the feed solution. The example method includes regenerating the draw solution from the diluted draw solution. The example method includes recirculating the draw solution that has been regenerated through the second side of the forward osmosis system.

(6) Methods of dewatering a solution are disclosed. An example method includes introducing feed solution having one or more permeable solutes into a first side of a forward osmosis system. The example method includes circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes in the feed solution. The example method includes generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution. The example method includes producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a higher concentration of the at least one species of the one or more permeable solutes than the feed solution.

(7) Methods of dewatering an alcoholic beverage using forward osmosis are disclosed. An example method includes introducing an alcoholic beverage into a first side of a forward osmosis system. The example method includes circulating a draw solution in a second side of the forward osmosis system, the draw solution having an alcohol concentration greater than or equal to the alcoholic beverage. The example method includes generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution. The example method includes producing a product stream including a concentrated alcoholic beverage from the first side of the forward osmosis system. The example method includes regenerating the draw solution from the diluted draw solution. The example method further includes producing a permeate stream from the diluted draw solution.

(8) Systems for dewatering an alcoholic solution are disclosed. An example system includes a forward osmosis element including at least one selectively permeable forward osmosis membrane separating a first side of the forward osmosis element from a second side of the forward osmosis element. The example system includes an alcohol solution in the first side. The example system includes a draw solution in the second side, the draw solution having a higher alcohol weight percentage than the alcohol solution.

(9) Methods of dewatering a solution are disclosed. An example method includes introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system. The example method includes circulating a draw solution having one or more permeable solutes and one or more impermeable solutes therein through a second side of the forward osmosis system. The example method includes generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution. The example method includes producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a desired concentration of the at least one species of the one or more permeable solutes; wherein a combined osmotic pressure of the one or more permeable solutes and the one or more impermeable solutes in the draw solution is greater than an osmotic pressure of the concentrated feed solution

(10) Features from any of the disclosed embodiments may be used in combination with one another, without limitation. In addition, other features and advantages of the present disclosure will

become apparent to those of ordinary skill in the art through consideration of the following detailed description and the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) For better understanding, the like elements have been designated by like reference numbers throughout the various accompanying figures. Understanding that these drawings depict only embodiments of the invention and are not therefore to be considered to be limiting of its scope, embodiments of the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

(2) FIG. **1** is a block diagram of a co-current forward osmosis system for removing one or more components from solutions, according to examples described herein;

(3) FIG. **2** is a block diagram of a countercurrent system for removing one or more components from solutions, according to examples described herein;

(4) FIG. **3** is a block diagram of a countercurrent forward osmosis system for dewatering of alcoholic solutions, according to examples described herein;

(5) FIG. **4** is a block diagram of forward osmosis system for dewatering alcoholic solutions including a distillation apparatus for recovery of the draw solution by distillation, according to examples described herein;

(6) FIG. **5** is a block diagram of a countercurrent forward osmosis system for dewatering alcoholic solutions with a reverse osmosis element for recovery of the draw solution via reverse osmosis, according to examples described herein;

(7) FIG. **6** is a block diagram of a forward osmosis system for dewatering alcoholic solutions configured for recovery of the draw solution by reverse osmosis and distillation, according to examples described herein;

(8) FIG. **7** is a block diagram of a forward osmosis system for dewatering an alcoholic solution, according to examples described herein;

(9) FIG. **8** is a block diagram of a forward osmosis system for dewatering an alcoholic solution and configured for recovery of a draw solution via multiple reverse osmosis operations, according to examples described herein;

(10) FIG. **9** is a block diagram of a forward osmosis system for dewatering a solution and configured for recovery of a draw solution via multiple reverse osmosis operations, according to examples described herein;

(11) FIG. **10** is a flow diagram of a method for dewatering a solution, according to examples described herein;

(12) FIG. **11** is a flow diagram of a method for dewatering an alcoholic solution via forward osmosis, according to examples described herein;

(13) FIG. **12** is a block diagram of a forward osmosis system for concentrating a feed solution, according to examples described herein;

(14) FIG. **13** is a block diagram of a forward osmosis system for concentrating a feed solution, according to examples described herein;

(15) FIG. **14** is a block diagram of a forward osmosis system for concentrating a feed solution, according to examples described herein;

(16) FIG. **15** is a block diagram of a draw recovery system, according to examples described herein;

(17) FIG. **16** is a block diagram of a distillation apparatus, according to examples described herein;

(18) FIG. **17** is a flow diagram of a method for concentrating a solution, according to examples described herein;

(19) FIG. **18** is a flow diagram of a method for concentrating an alcoholic solution via forward osmosis, according to examples described herein;

(20) all arranged in accordance with at least some embodiments of the present disclosure.

DETAILED DESCRIPTION

(21) Embodiments described herein relate to methods for removing water or water and permeable solutes from solutions having one or more permeable solutes therein using forward osmosis (FO), and systems for the same. One or more solutes (e.g., dissolved, dispersed, or suspended components of a solvent system) can be selectively separated from one or more solvents using FO. The one or more solutes can include at least partially dissolved, dispersed, or suspended sugar(s), alcohol(s), volatile organic compounds (VOCs), proteins, salt(s), sugar alcohol(s), or other components of liquid systems that are capable of filtration (e.g., retention or removal) at a filtration membrane via FO, or combinations of any of the foregoing. Solutes may include permeable solutes that are capable of crossing the FO membrane, such as ethanol, methanol, ethylene glycol, etc. Solutes may include impermeable solutes that are substantially incapable of crossing the FO membrane (excepting negligible amounts of flux), such as sodium chloride, magnesium chloride, magnesium sulfate, glycerol, fructose, glucose, sucrose, polyethylene glycol, etc.

(22) In example methods and systems disclosed herein, a first solution (e.g., feed solution) having a lower concentration of one or more permeable solutes is passed along a first side of a semipermeable membrane while a second solution (e.g., draw solution) of a higher osmotic pressure (e.g., higher concentration of the one or more permeable solutes) is passed along a second side of the semipermeable membrane. One or more solvents (e.g., water) and/or permeable solutes (e.g., methanol, ethanol, ethylene glycol, lithium, lactic acid, acetic acid, citric acid, boron and boron oxides, hydroxide salts, ammonia etc.) are drawn from the feed solution into the draw solution, while one or more impermeable solutes (e.g., solutes that are substantially incapable of passing through the FO membrane (except in negligible amounts), such as proteins, flavor compounds, glucose, sucrose, fructose, glycerol, etc.) are selectively retained, thereby concentrating the feed solution while diluting the draw solution. While it is understood that permeability of a material is dependent upon membrane materials relative to the specific material, as used herein, the terms “permeable” and “impermeable” refer to the permeability of specific solutes across an FO membrane (ignoring permeability of the same solutes relative to RO membranes). In some embodiments, the impermeable solutes could constitute matter that is concentrated in the feed solution to produce feed concentrate. In some embodiments, the impermeable solutes present in the draw solution can provide the driving force (osmotic pressure differential) for the concentration process. The retention by the semipermeable membrane of one or more impermeable solutes may be 99% or higher, or 95% or higher, or 90% or higher and may be specific for that particular membrane and solute combination and may be affected by operating conditions such as temperature, flux, etc. The retention by the semipermeable membrane of one or more permeable solutes may be less than 99%, or may be less than 95%, or 90% or less and may be specific for that particular membrane and solute combination and may be affected by operating conditions such as temperature, flux, etc. The net flux of one or more permeable solutes and/or impermeable solutes across the FO membranes herein may be zero (e.g., some positive or negative fluxes are balanced out across the entirety of the FO membrane). This process may be carried out with both feed and draw solutions at common, atmospheric pressures. Specific permeable and/or impermeable solutes may be preferentially rejected by the FO membrane similar to reverse osmosis (RO).

(23) When concentrating feed streams having multiple components (e.g., water, ethanol, carbohydrates, etc.) by forward osmosis, retention of one component (e.g., ethanol) versus the other (e.g., carbohydrates) may be poor (e.g., less than 70%). By adding one or more specific components (e.g., permeable solute(s) such as ethanol and/or impermeable solute(s) such as glycerol, sucrose, etc.) selected from the multiple components (e.g., ethanol, ethylene glycol,

glycerol, sucrose, etc.) to the draw solution, the separation systems herein may retain one or more specific components (e.g., ethanol) in the feed stream while at least some of the other components or solvent(s) (e.g., water) in the feed are at least partially removed (e.g., dewatering). The permeable solute may be selectively removed from the other multiple components (e.g., carbohydrates) by minimizing the concentration of permeable solute in the draw solution. Additional permeable solute may be further removed by dilution of the feed stream before concentration by forward osmosis, during, or after, increases the total amount of water and permeable solute removed. Methods of reconstituting the dewatered alcoholic solutions present in the draw solutions that leverage various pressure driven membrane and distillation processes are also disclosed herein.

(24) Examples of methods and systems disclosed herein utilize forward osmosis for separation of liquids. Forward osmosis (FO) generally refers to the process of transporting liquids (e.g., water) across a semipermeable membrane while rejecting a solute. The FO process dewaters (e.g., concentrates) feed streams using a semipermeable membrane and a draw stream having a higher concentration of one or more components in the feed stream to provide higher osmotic pressure. The driving force in FO, the transfer of at least one liquid and/or solute component (e.g., water) from the feed stream to the draw stream, is osmotic pressure difference(s) generated from chemical potential of the two streams, unlike typical hydrostatic pressure-driven membrane processes. Example methods and systems disclosed can be specifically used for dewatering alcoholic solutions. Dewatering generally refers to the removal of water from a material (e.g., a solid or another (aqueous) solution). Separation systems including FO elements may be used to treat solutions (e.g., aqueous solutions having ethanol therein), which can include alcoholic beverages. Generally, any solution (e.g., a liquid containing water, alcohol, and one or more other permeable solutes) may be dewatered using the systems and methods described herein. The alcohol included in the feed solutions (e.g., alcoholic solutions) may generally be any alcohol, such as ethanol, methanol, etc. Example (alcoholic) solutions may include beer, malt beverages, distilled liquors, a fermentation broth (e.g., for ethanol production), flavor extraction(s), dye extraction(s), wine, or combinations thereof.

(25) While certain solutions, distillates, permeates, concentrates, products, etc., are described as “streams” herein, it is understood that the “streams” may contain said solutions, distillates, permeates, concentrates, products, etc. The term “stream(s)” as used herein is intended to include the meaning of a flow or volume of a solution and is not intended to require that the stream has a constant flow.

(26) Example FO systems and methods disclosed herein allow solutions to be dewatered at ambient pressures and temperatures while allowing selective retention of permeable solute(s) such as alcohol(s), volatile organic compounds (VOCs), sugar(s), etc. Advantageously, the dewatered solution may be transported and shipped in a manner that may be more efficient than transporting and/or shipping the fully hydrated solution. The dewatered solution may then be reconstituted prior to consumption. In this manner, for example, beer may be dewatered to form a dewatered beer solution and may be packaged and shipped in the dewatered form. The dewatered beer solution may have a higher concentration of alcohol than the beer solution, the same concentration of alcohol as the beer solution, or a reduced alcoholic concentration than the beer solution. On receipt, a consumer (or retail outlet) may reconstitute the dewatered beer solution for consumption. The dewatered beer solution may be reconstituted by the addition of carbonated water or by the consumer or a beverage machine to produce a beer or reduced alcoholic beer (e.g., a 3.2% ABW beer, or a non-alcoholic beer). The dewatered beer solution may be reconstituted by the addition of an alcoholic solution (e.g., vodka) and carbonated. Example systems and methods described herein may advantageously employ FO to conduct the dewatering, which may improve flavor retention in the dewatered solution, such that the reconstituted solution (e.g., reconstituted dewatered beer solution) retains a flavor identical or similar to that of the original solution prior to dewatering.

Accordingly, the FO systems and techniques disclosed herein may dewater an alcoholic solution without significantly altering or degrading the nutrients or components of the product stream or the flavor(s) of the alcoholic beverage (e.g., when reconstituted). Benefits of concentrating (e.g., dewatering) said solutions may include reduced transportation costs, reduced loss of VOCs, manufacture of a reduced alcoholic solution (e.g., non-alcoholic beer, alcohol-free flavor extracts) increased stability and shelf life, and the manufacture of a unique consumer product (e.g., a dewatered alcoholic beverage).

(27) Benefits and advantages of examples described herein are provided to facilitate appreciation of example systems described herein. It is to be understood that the benefits and advantages are exemplary only, and not all examples described herein may have all, or even any, of the benefits and advantages described.

(28) Example systems for separating liquid components (e.g., dewatering) of a solution or mixture herein may generally include a primary fluid input providing a feed stream containing a feed solution (e.g., an alcoholic beverage or solution); an FO membrane; and at least one fluid output including a concentrated feed stream containing the dewatered alcoholic solution (e.g., alcoholic solution concentrate). A diluted draw stream containing a diluted draw solution may be produced which can provide a second output, a permeate stream generally containing mostly water. Example systems herein may also include a draw stream input providing a draw stream containing the draw solution having a higher concentration of one or more components (e.g., permeable and/or impermeable solutes) than the feed stream and/or concentrated feed stream. While alcoholic solutions, including alcoholic beverages are used as examples of solutions having permeable solutes herein, it is understood that permeable solutes in addition to or in place of alcohol are also considered in each of the examples and can be used interchangeably or additionally with the example alcohols described.

(29) FIG. **1** is a block diagram of a co-current FO system **100** for removing one or more components from a solution. The system **100** is configured as a co-current system. That is, the bulk flow of both the feed stream **112** and the draw stream **122** travels in the same direction through an FO element(s) **110** in the system **100**. The system **100** includes a feed stream source **114** which provides at least some of the feed stream **112** to at least one FO element **110**. The system **100** further includes at least one draw stream source **124** fluidly coupled to the at least one FO element **110** and configured to provide the draw stream **122** to the at least one FO element **110**. The feed stream **112** may be present in, and travel through, the FO element **110** in a first side **115** thereof. The draw stream **122** may be present in, and travel through, the FO element **110** in a second side **125** thereof. The first side **115** and the second side **125** are separated by at least one FO membrane **130** disposed therebetween. The at least one FO element **110** can include an FO housing (e.g., a fluid tight container or assembly) at least partially defining an interior region in which the FO membrane **130** and first and second sides **115** and **125** are located. While the first side **115** is described as the feed side and the second side **125** is described as the draw side, the designations first and second are merely for differentiation between the elements and not meant to be limiting of the elements or configuration of the system **100**. For example, the first and second sides **115** and **125** can include separate volumes, layers, serpentine paths, etc., so long as the first side **115** is at least partially chemically separated from the second side **125**, such as via at least one FO membrane **130** therebetween.

(30) As the feed stream **112** and draw stream **122** travel through the FO element **110**, one or more permeable solutes of the feed stream **112** can permeate through the FO membrane **130** into the draw stream **122**. The feed stream **112** can include a feed solution to be concentrated (e.g., dewatered), such as a solution containing any combination of permeable solutes (e.g., alcoholic solution) disclosed herein. The draw stream **122** can include a draw solution having of one or more common components (e.g., solvent(s), permeable and/or impermeable solute(s)) of the feed stream **112** therein. For example, the draw stream **122** can include one or more of alcohol, water, glucose,

ethylene glycol, sucrose, fructose, glycerol, lactic acid, one or more dissolved salts, or any other component found in the feed stream **112**. The presence or addition of one more permeable solutes (e.g., alcohol) and/or impermeable solutes (e.g., glycerol) to the draw stream **122** may be effective to selectively control the retention of one more permeable solutes in feed stream **112** as it is dewatered. Equal or higher amounts of the one or more common components (e.g., permeable and/or impermeable solutes in both the feed and draw streams) of the feed stream **112** present in the draw stream **122** can limit or prevent said one or more common components from crossing the FO membrane **130** from the feed stream **112** into the draw stream **122**. Reduced amounts of the one or more common components (e.g., permeable and/or impermeable solutes in both the feed and draw streams) of the feed stream **112** that are present in the draw stream **122** may allow the one or more common components to cross the FO membrane **130** from the feed stream **112** into the draw stream **122**. For example, an equal or higher amount of alcohol and ethylene glycol present in the draw stream **122** than in the feed stream **112** can result in water being preferentially removed from the feed stream **112** via the FO membrane **130** while net alcohol and ethylene glycol amounts are retained. In the absence of alcohol in the draw stream **122**, net transfer of alcohol may readily occur from the feed stream **112** to the draw stream **122** such that the final concentrated feed stream **116** would have a reduced alcohol concentration. In some embodiments, a combination of at least two permeable solutes and/or impermeable solutes in the draw stream can be used to provide a sufficient amount of osmotic pressure effective to limit migration of one or more permeable solutes (e.g., ethanol) from the feed stream to the draw stream. For example, a combination of one or more permeable solutes and impermeable solutes may induce a collectively higher osmotic pressure in the draw stream than the osmotic pressure present in the feed stream, thereby inducing selective permeation of the solvent (e.g., water) across the FO membrane while the permeable solute (e.g., ethanol) in the feed stream is substantially entirely retained. For example, an equal or higher amount of the combination of alcohol and glycerol present in the draw stream **122** over the amount of ethanol in the feed stream **112** can result in water being preferentially removed from the feed stream **112** via the FO membrane **130** while alcohol is retained. In some embodiments, at least one of the permeable or impermeable solutes may not be common to the feed stream and the draw stream.

(31) As the feed stream **112** is concentrated in the FO element **110** by removal of at least one fluid component (e.g., solvent such as water) thereof through the FO membrane **130**, a concentrated feed stream **116** (e.g., concentrated alcoholic solution) is produced. The concentrated feed stream **116** can be directed to one or more downstream product components **118** fluidly coupled to the first side **115** of the FO element **110**. As the draw stream **122** (e.g., draw solution) is diluted by addition of one or more components from the feed stream **112** (e.g., water) via the FO membrane **130**, the system **100** produces a diluted draw stream **126** (e.g., draw stream having a similar or higher concentration of one or more components thereof such as water, than were present when the draw stream entered the FO element **110**). The diluted draw stream **126** can be directed to one or more downstream draw components **128** fluidly coupled to the second side **125** of the FO element **110**.

(32) The feed stream source **114** can include one or more of a tank, a pressurized pump, a valve, a pipe, a conduit, a hose, a temperature control element, etc. The feed stream source **114** is fluidly coupled (e.g., plumbed) to the first side **125** of the FO element **110**. The feed stream source **114** can be configured to selectively provide a desired feed rate and/or pressure of the feed stream **112** to the FO element **110**. The draw stream source **124** can include one or more of a tank, a pressurized pump, a valve, a pipe, a conduit, a hose, a temperature control element, etc. The draw stream source **124** is fluidly coupled to the second side **125** of the FO element **110**. The draw stream source **124** can be configured to selectively provide a desired feed rate and/or pressure of the feed stream **112** to the FO element **110**.

(33) The FO element **110** may be any FO element or array of elements, including but not limited to, spiral wound FO element or standard or baffled plate and frame FO element(s). The FO

membrane(s) **130** of the FO element(s) **110** can include any permeable membrane such as a selectively permeably membrane configured to allow passage of one or more components of the feed stream therethrough, while rejecting one or more components of the feed stream. In some examples, the FO membrane **130** may be polymeric membrane including a polymeric material therein such as a polyamide, a cellulose acetate, aramid, poly(vinylidene fluoride), polyacrylonitrile, polysulphone, or any other polymer material suitable for use as a FO membrane. In some examples, the FO membrane may include thin film composite membrane including one or more of any of the polymer materials disclosed above. In some examples, the FO membrane **130** may include one or more support layers supporting one or more functional layers, such as one or more polyamide thin film layers. In some embodiments, the FO membrane **130** can include an array of FO membranes that may be in arranged parallel or in series, or in any combination of parallel and series. Examples of FO elements, FO membranes, and components thereof suitable for use in the FO systems described herein can include any of those described in U.S. Pat. No. 8,920,654, filed Sep. 30, 2011; U.S. patent application Ser. No. 14/137,903 filed Dec. 20, 2013; PCT Application PCT/US2014/029227 filed Mar. 14, 2014; and PCT Application PCT/US2014/029332 filed Mar. 14, 2014, each of which is incorporated by this reference in its entirety for any purpose.

(34) The one or more downstream product components **118** fluidly coupled to the first side **115** can include one or more of a pipeline, a storage tank, a point of use device, a conduit, a pressure pump, a temperature control device (e.g., refrigerator or heater), a packaging apparatus, one or more FO elements, individual packages (e.g., kegs, bottles, etc.). The one or more downstream draw components **128** can include one or more of a pipeline, a conduit, a storage tank, a pump, a temperature control device (e.g., refrigerator), one or more draw solution recovery (e.g., regeneration) apparatuses, a waste storage, a permeate storage, etc. In some embodiments, the one or more draw solution recovery or regeneration apparatuses can include reverse osmosis (RO) elements (e.g., low rejection or standard reverse osmosis apparatuses) or one or more distillation apparatuses.

(35) In use, a feed solution (e.g., 5% ABW alcohol) may be pressurized by a pump (e.g., feed stream source **114**) forming low-pressure feed stream **112**. The at least one FO element **110** may receive the feed stream **112** and dispense concentrated feed stream **116** (e.g., 30% ABW, at 2 gpm). The draw solution (e.g., 40% ABW at 30 gpm) may be pressurized by a pump (e.g., draw stream source **124**) to form low-pressure draw stream **122**. The draw stream **122** may include water, a permeable solute (e.g., ethanol), and at least one impermeable solute (e.g., sodium chloride, magnesium chloride, magnesium sulfate, glycerol, fructose, glucose, sucrose, polyethylene glycol). FO element **110** may receive low-pressure draw stream **122** and dispense a dilute draw stream **126** (e.g., 30% ABW at 40 gpm). The permeable solutes in the draw and/or feed stream(s) may include any of the permeable solutes disclosed herein. In the FO element **110**, at least some water may permeate from the feed stream **112** to the draw stream **122** across at least one FO membrane **130** therebetween. At least some alcohol or other permeable solute(s) may be retained in the feed stream **112**, such that the total amount of alcohol or other permeable solutes is maintained in the feed stream **112** while the feed stream **112** is dewatered, resulting in concentrated feed stream **116** (e.g., 30% ABW).

(36) In some embodiments, the relative alcohol content in the concentrated feed stream **116** (as compared to the feed stream **112**) can be increased by at least about 5% ABW, such as about 5% ABW to about 50% ABW, about 10% ABW to about 40% ABW, about 15% ABW to about 35% ABW, about 20% ABW to about 40% ABW, about 25% ABW to about 35% ABW, or less than about 60% ABW. In some embodiments, at least some alcohol can permeate from the draw stream **122** to the feed stream **112**. Alternatively, at least some alcohol (and/or other permeable solute(s)) may permeate from the feed stream **112** to the draw stream **122** such that the alcohol (and/or other permeable solute(s)) concentration is decreased in the concentrated feed stream **116**. For example,

the relative alcohol content of the concentrated feed stream **116** can decrease by at least about 1% ABW as compared to the feed stream **112**, such as about 1% ABW to about 40% ABW, about 5% ABW to about 20% ABW, or less than about 40% ABW. The relative alcohol concentration can be decreased by a selected amount such that the alcohol is largely removed (e.g., stream **116** less than about 0.1% ABW). While alcohol is used as an example herein, similar or identical results to any of those disclosed herein can be obtained with other permeable solutes of the feed and draw streams, such as ammonia, ethylene glycol, dissolved salts, etc. (e.g., wherein the concentration of the component is in weight % rather than % ABW).

(37) In some examples (not shown) having an array of FO membranes **130** (e.g., in a baffled plate and frame FO element) or an array of FO elements **110**, the feed stream **112** and the draw stream **122** may be received by the same FO element **110** at the beginning of the array, and the concentrated feed stream **116** and the diluted draw stream **126** may be dispensed by the same FO element at the end of the array. Co-current operation may be used with spiral wound elements. Control of the trans-membrane pressure, operating with a positive and low (e.g., 1 to 5 psi) pressure from the feed stream to the draw stream may improve the permeable solute rejection and have significant impacts on the separation of draw components from the feed. Suitable pressures can include about 0.5 psi or more, such as about 0.5 psi to about 10 psi, about 1 psi to about 8 psi, about 2 psi to about 6 psi, about 3 psi to about 5 psi, about 0.5 psi to about 2 psi, about 2 psi to about 4 psi, about 1 psi to about 5 psi, less than about 5 psi, or less than about 3 psi.

(38) In a co-current flow regime, the final concentration of alcohol (and/or other permeable or impermeable solute(s)) in the draw stream **122** and/or diluted draw stream **126** may be greater than or equal to the final alcohol (and/or other permeable solute(s)) concentration of the concentrated feed stream **116**, for example 30% ABW. In some examples, an excess of alcohol may be used in the draw stream **122** and/or diluted draw stream **126** to maintain high retention of alcohol in feed streams **112** as they are dewatered. An excess of alcohol (or other permeable draw component) may be used to retain alcohol in the feed because the draw stream is diluted as water transfers from the feed stream to the draw stream, known as dilutive concentration polarization. Therefore, an excess of alcohol in the draw stream may be used to have an effective concentration difference. In addition, water permeating through the membrane may hydrogen bond with some permeable solutes (e.g., alcohol) and increase the permeation relative to permeable solutes that do not hydrogen bond with water. In some embodiments, the excess alcohol (and/or other permeable solute(s)) remains in excess even after dilution of the draw solution, the amount of which may be present in the draw stream **122** or the diluted draw stream **126**. In some examples, an excess of greater than 0% ABW to about 60% ABW over the feed stream **112** alcohol content may be used. For example, the final concentration of alcohol in the diluted draw stream **126** can be at least about 1% ABW greater than the final alcohol concentration of the concentrated feed stream **116**, such as about 1% ABW to about 60% ABW greater, about 5% ABW to about 50% ABW greater, about 10% ABW to about 40% ABW greater, about 15% ABW to about 35% ABW greater, about 20% ABW to about 40% ABW greater, about 25% ABW to about 35% ABW greater, about 1% ABW to about 20% ABW greater, about 20% ABW to about 40% ABW greater, about 40% ABW to about 60% ABW greater, about 1% ABW to about 5% ABW greater, about 1% ABW to about 10% ABW greater, about 5% ABW to about 15% ABW greater, about 10% ABW to about 20% ABW greater, or less than about 60% ABW greater than the final alcohol concentration of the concentrated feed stream **116**. It has been discovered that a diluted draw stream **126** (and precursor draw stream **122**) having a final alcohol concentration (or combined permeable solute and/or impermeable solute concentration) at least about 5% ABW greater (e.g., 10% ABW greater) than the final alcohol content of the associated concentrated feed stream **116** are particularly effective at producing a desired level of alcohol in the concentrated feed stream **116**. For example, a final alcohol concentration of a concentrated feed solution may be about 30% ABW while the final alcohol concentration of the diluted draw stream can be at least about 40% ABW.

(39) The species of the one or more components (e.g., solvent(s) such as water and/or permeable solute(s)) of the feed stream **112** that permeate the FO membrane **130** into the draw solution and extent (e.g., amount) of the permeation can be selectively adjusted by controlling one or more of the amount (e.g., concentration) and/or species of one or more permeable solutes (and/or impermeable solutes) of the draw solution of draw stream **122** (e.g., alcohol content), the surface area of the FO membrane **130** in contact with the feed and draw streams **112** and **122**, the feed rate of one or both of the feed and draw streams **112** and **122** into the FO element **110**, the pressure of one or both of the feed and draw streams **112** and **122** into the FO element **110** (and related hydrostatic pressure across the FO membrane **130**), or the temperature of one or both of the feed and draw streams **112** and **122** into the FO element **110**. Specifically, the amount of excess alcohol (e.g., ethanol) and/or other permeable or impermeable solutes used in the draw stream **122** may be dependent on one or more of flow rate(s), dewatering rates, recovery rate(s), temperature, feed stream composition, draw stream composition, membrane surface area in contact with the streams, type of membrane, pressure in the first and/or second side, etc.
(40) Each of the different components of the systems disclosed herein can be operably (e.g., fluidly) coupled together via one or more conduits (e.g., pipes, tubes, hoses, etc.), valves, pumps, etc. For brevity, the components of the block diagrams are shown with arrows therebetween. It should be understood that each of the arrows may represent one or more conduits, valves, tanks, pumps, or other fluid connections between components of the systems.
(41) In some embodiments, the FO system or array of elements therein may be configured in a countercurrent configuration. FIG. **2** is a block diagram of a countercurrent system **200** for removing one or more components from solutions. In a countercurrent system, the feed stream and draw stream travel through the FO element in opposing directions. Countercurrent processing may allow the use of a reduced amount of permeable and impermeable solute(s) compared to co-current flows because the permeable and impermeable solute(s) concentration and osmotic differential between the feed stream and draw stream may be essentially constant. Countercurrent processing may allow the use of a reduced amount of permeable and impermeable solute compared to co-current processing because the concentration differential between the feed stream and draw stream may be essentially constant. The system **200** includes a feed stream source **114** which supplies a feed stream **112**, at least one FO element **110** including at least one FO membrane **130**, and one or more downstream product components **118** configured to receive the concentrated feed stream **116**, as described above. The system **200** includes draw stream source **124** which supplies a draw stream **122**, and one or more downstream draw components **128** which contain the diluted draw stream **126**. As shown, the direction of travel of the draw stream **122** through the second side **125** of the FO element **110** is in the opposite direction of the flow of the feed stream **112** through the first side **115** of the FO element **110**. In some examples, an advantage to the countercurrent configuration may be that the initial draw stream **122** alcohol and/or other permeable solute(s) concentration may be equal to or not necessarily significantly exceed (e.g., only about 1% ABW to about 5% ABW) the feed stream **112** concentrate alcohol concentration. In some examples, a small excess in draw stream **122** alcohol and/or other permeable solute(s) content (over the amount for effective dewatering of the alcohol solution) may be used to replace or offset alcohol and/or other permeable solute(s) lost in draw stream recovery (nanofiltration (NF)/RO permeate or distillation for example).
(42) In some examples, a small loss of alcohol (e.g., greater than 0% ABW to about 3% ABW) in the feed stream **112** and/or concentrated feed stream **116** may be used (e.g., tolerated) to avoid adding excess alcohol to the draw stream **122**. In such examples, the amount of alcohol in the draw stream **122** can be equal to or slightly less than (e.g., 0% ABW to 3% ABW less than) the alcohol content in the feed stream **112** and/or concentrated feed stream **116**.
(43) During use, the feed solution (e.g., 5% ABW at 12 gpm) may be pressurized by a pump (e.g., feed stream source **114**) to form a low-pressure feed stream **112**. FO element **110** may receive the

feed stream **112** and dispense concentrated feed stream **116** (e.g., 30% ABW at 2 gpm). The draw solution (e.g., 30% ABW at 2 gpm) may be pressurized by a second pump (e.g., draw stream source **124**) to form low-pressure draw stream **122**. The FO element **110** may receive the low-pressure draw stream **122** and dispense diluted draw stream **126** (e.g., 5% ABW at 12 gpm). Water may permeate from the feed stream **112** to the draw stream **122** via the FO membrane **130** therebetween.

(44) In some embodiments, the FO system can include more than one FO element. In some embodiments, the at least one FO element or array (e.g., parallel and/or series array) of FO elements may be plumbed in a countercurrent configuration with intermediate injection of high concentration draw solution or pure permeable and/or impermeable solutes (e.g., alcohol) at intermediate stages along the array. Such configurations can allow permeable and impermeable solute(s) to be added to a system, increasing the driving force (e.g., osmotic pressure induced by chemical potential) while balancing the permeable and impermeable solute (e.g., ethanol) concentration in the draw solution(s) along the FO membrane array.

(45) FIG. **3** is a block diagram of a countercurrent FO system **300** for dewatering of alcoholic solutions. The countercurrent FO system **300** includes one or more (ports for) intermediate injections of alcohol (or high concentration alcohol solutions) into the diluted draw stream. The system **300** includes a plurality of FO elements **110***a*-**110***c* fluidly coupled (e.g., plumbed) in series. The system **300** includes a feed stream source **114** operably coupled to a first FO element **110***a*. The first FO element **110***a* includes a first FO membrane **130***a* at least partially defining a first side **115***a* and a second side **125***a* therein. The first side **115***a* of the first FO element **110***a* is fluidly coupled to a second FO element **110***b*. The second FO element **110***b* includes a second FO membrane **130***b* at least partially defining a first side **115***b* and a second side **125***b* therein. The first side **115***b* of the second FO element **110***b* is fluidly coupled to a third FO element **110***c*. The third FO element **110***c* includes a second FO membrane **130***c* at least partially defining a first side **115***c* and a second side **125***c* therein. The first sides **115***a*-**115***c* of the FO elements **110***a*-**110***c* are coupled together to form a collective first side of the system **300**. The first side of the system **300** can include one or more components in fluid communication with the first sides **115***a*-**115***c* of the FO elements **110***a*-**110***c*, such as the feed stream source **114**.

(46) As the feed stream **112** passes through the series of FO elements **110***a*-**110***c*, the feed stream **112** becomes more and more concentrated. For example, as the feed stream **112** passes through the first side **115***a* of the first FO element **110***a*, the feed stream **112** is dewatered (e.g., concentrated) to form concentrated feed stream **116***a* having a higher concentration of alcohol than the feed stream **112**. As the concentrated feed stream **116***a* is passed through the first side **115***b* of the second FO element **110***b*, the concentrated feed stream **116***a* is further concentrated (e.g., dewatered) to form second concentrated feed stream **116***b* having a higher concentration of alcohol than one or both of feed stream **112** and concentrated feed stream **116***a*. As the second concentrated feed stream **116***b* is passed through the first side **115***c* of the third FO element **110***c*, the second concentrated feed stream **116***b* is further concentrated to form third concentrated feed stream **116***c* having a higher concentration of alcohol than one or all of feed stream **112** and concentrated feed stream(s) **116***a* and/or **116***b*. The third concentrated feed stream **116***c* can be directed to one or more downstream product components **118**, such as any of those disclosed herein.

(47) On the second side of the system **300**, a draw stream source **124** configured to provide a draw stream **122** to the system **300**. The draw stream source **124** is operably coupled to the second side **125***c* of the third FO element **110***c*. As the draw solution is passed through the second side **125***c*, the draw stream **122***a* is diluted to form diluted draw stream **126***a*. Diluted draw stream **126***a* is directed to downstream draw components **128***a*. Downstream draw components **128***a* can include one or more of at least one conduit (e.g., pipe), a pump, a valve, a tank, an injection port, a mixing apparatus, etc. For example, the downstream draw components **128***a* can include a conduit having an injection port wherein an injection of one or more components (e.g., alcohol and/or glycerol) of

the draw stream **122***a* may be added to the diluted draw stream **126***a* to form a first reconstituted draw stream **122***b*. The alcohol injection port can be configured to provide an injection, titer, or stream of alcohol (or other draw stream component(s)) sufficient to selectively control (e.g., raise) the concentration of alcohol (or other draw stream component(s)) in the diluted draw stream **126***a*. For example, the alcohol injection port can be used to provide an injection **138***a* configured to raise the concentration of alcohol at least about 5% ABW over the diluted draw stream **126***a*, such as raise the concentration to at least about 10% ABW more than the alcohol content of the diluted draw stream **126***a*, at least about 5% ABW over the concentrated feed stream **116***a* or **116***b*, at least about 10% ABW more than the alcohol content of the second concentrated feed stream **116***a* or **116***b*, or at least as high as the draw stream **122***a*. The downstream draw components **128***a* are operably coupled to the second side **125***b* of the second FO element **110***b*.

(48) The first reconstituted draw stream **122***b* can be directed through the second side **125***b* of the second FO element **110***b* to draw one or more components out of the feed stream present in the first side **115***b* thereof. As the first reconstituted draw stream **122***b* absorbs components (e.g., water) from the feed solution in the second FO element **110***b*, the reconstituted draw stream **122***b* is diluted to form a second diluted draw stream **126***b*. The second side **125***b* of the second FO element **110***b* can be fluidly coupled to one or more downstream draw components **128***b*. The one or more downstream draw components **128***b* can be similar or identical to one or more downstream draw components **128***a* disclosed above. For example, the second diluted draw stream **126***b* can be directed from the second side **125***b* through one or more of a conduit, a pump, or mixing tank. The one or more downstream draw components **128***b* can include a second alcohol injection port wherein alcohol (or any other draw stream component) can be added to the second diluted draw stream **126***b* to control the concentration of the alcohol therein. The second alcohol injection port can be configured to provide an injection, titer, or stream of alcohol (or other draw solution components) to the second diluted draw stream **126***b* sufficient to selectively control the concentration of alcohol in the second diluted draw stream **126***b*. For example, the alcohol injection port can be used to provide a second injection **138***b* configured to raise the concentration of alcohol (or other component(s) of the draw solution) by at least about 5% ABW over the second diluted draw stream **126***b*, such as at least about 10% ABW more than the alcohol content of the second diluted draw stream **126***b*, at least about 5% ABW over the concentrated feed stream **116***a*, at least about 10% ABW more than the alcohol content of the second concentrated feed stream **116***b*, at least about 5% ABW over the feed stream **112**, at least about 10% ABW more than the alcohol content of the feed stream **112**, at least as high as the feed stream **112**, or at least as high as the draw stream **122***a*. The downstream draw components **128***b* are operably coupled to the second side **125***a* of the firsts FO element **110***a*.

(49) The second reconstituted draw stream **122***c* can be directed through the second side **125***a* of the first FO element **110***a* to draw one or more components out of the feed stream **112** present in the first side **115***a* thereof. As the second reconstituted draw stream **122***c* absorbs components (e.g., water) from the feed solution in the first FO element **110***a*, the second reconstituted draw stream **122***c* is diluted to form a third diluted draw stream **126***c*. The second side **125***a* of the first FO element **110***a* can be fluidly coupled to one or more downstream draw components **128***c*, such as any downstream draw components disclosed herein. For example, the third diluted draw stream **126***c* can be directed from the second side **125***a* through one or more of a conduit, a pump, or a storage tank.

(50) The second sides **125***a*-**125***c* (and portions of the system **300** in fluid communication therewith) can collectively form a second side of the system **300**. The second side of the system is separated from the first side of the system by the FO membrane(s) and only has contact therewith via the FO membrane(s). As used in some examples herein, the first side can be a feed side and the second side can be a draw side.

(51) As shown in FIG. **3**, in some examples there may be multiple intermediate injection stages,

while in other examples there may only be one intermediate injection stage (e.g., port). In some embodiments, the system **300** can include one or more outputs between any of the FO elements on one or both of the first (feed) side or second (draw) side. For example, an output such as a valve and drain line can be disposed between the first FO element **110***a* and the second FO element **110***b*, and second FO element **110***b* and the third FO element **110***c*. The output(s) can allow selective capture of the concentrated feed streams **116***a* and **116***b* prior to the end of the system **300** (e.g., the one or more downstream product components **118**). In some embodiments, the system **300** can include one or more pumps between any of the FO elements on one or both of the first (feed) side or second (draw) side such as to control pressure or flow rates at any of the components of the system **300**. In some embodiments, rather than reconstituting the draw solution(s), the diluted draw solutions can be removed from the system at each FO element and a new draw solution can be introduced to the second side of each respective FO element via a new, distinct draw stream source.

(52) In some examples, feed solution may be pressurized by a pump (e.g., feed stream source **114**) to form low-pressure feed stream **112** (e.g., 5% ABW at 12 gpm). The first FO element **110***a* may receive low-pressure feed stream **112** and dispense concentrated feed stream **116***a* (e.g., 6.7% ABW at 8.7 gpm). The second FO element **110***b* or may receive the concentrated feed stream **116***a* and dispense the second further concentrated feed stream **116***b* (e.g., 11.3% ABW at 5.3 gpm). The third FO element **110***c* may receive the second concentrated feed stream **116***b* and dispense the third, further concentrated feed stream **116***c* (e.g., 30% ABW at 2 gpm). Draw solution may be pressured by pump (e.g., draw stream source **124**) to form low pressure draw stream **122***a* (e.g., greater than 30% ABW, 15% glycerol by weight (GBW), at 12 gpm). The third FO element **110***c* may receive low-pressure draw stream **122***a* and dispense diluted draw stream **126***a* (e.g., 23.5% ABW, 11.7% GBW, 15.3 gpm). An injection **138***a* of concentrated glycerol and water (e.g., 30% GBW at 16.7 gpm) may be combined with diluted draw stream **126***a* via an injection port, valve, and/or pump (e.g., downstream draw component **128***a*) to form a first reconstituted draw stream **122***b* (e.g., 11.25% ABW, 21.2% GBW, at 32 gpm). The second FO element **110***b* may receive the first reconstituted draw stream **122***b* and dispense diluted draw stream **126***b* (e.g., 10.2% ABW, 19.2% GBW, at 35.3 gpm). A second injection **138***b* of concentrated glycerol and water (e.g., 30% GBW at 17 gpm) may be combined with the second diluted draw stream **126***b*, such as by an injection port, valve, or a pump (e.g., downstream draw component **128***b*) to form second reconstituted draw stream **122***c* (e.g., 6.9% ABW, 22.7% GBW, at 52.3 gpm). The first FO element **110***a* may receive the second reconstituted draw stream **122***c* and dispense the third diluted draw stream **126***c* (e.g., 6.5% ABW, 21.4% GBW, at 55.7 gpm). The third diluted draw stream **126***c* may can be directed to one or more downstream draw components **128***c*. The third diluted draw stream **126***c* may be processed by any one of several draw solution recovery/regeneration techniques described herein.

(53) In some examples, the draw solution may be recovered (e.g., regenerated or reconstituted) by distillation. FIG. **4** is a block diagram of FO system **400** for dewatering alcoholic solutions, the system **400** including a distillation apparatus **140** for recovery (e.g., regeneration) of the draw solution by distillation. The system **400** includes a feed stream source **114** configured to supply the feed stream **112** to the first side **115** of at least one FO element **110** having at least one FO membrane **130** therein. The system **400** includes a draw stream source **124** configured to supply the draw stream **122** to the second side **125** of the FO element **110**. The system includes at least one downstream product component **118** fluidly coupled to the first side **115** of the FO element **110**. The system **400** further includes at least one regeneration apparatus fluidly coupled to the output orifice of the second side **125** of the FO element **110**.

(54) The at least one regeneration apparatus may be provided to at least partially restore the diluted draw stream **126** to the same composition (e.g., relative amounts) as the draw solution of draw stream **122**. As shown, the at least one regeneration apparatus can include distillation apparatus **140**. The distillation apparatus **140** can be fluidly coupled to and configured to receive the diluted

draw stream **126** from the second side **125** of the FO element **110** and concentrate at least one solute (e.g., permeable and/or impermeable solute) in the same via distillation. For example, the distillation apparatus **140** can be configured to produce a distillate stream **142** which may be used as or to augment the draw solution of draw stream **122**. The distillation apparatus **140** can include a distillation column or array (e.g., in series, in parallel, or both) of distillation columns. The distillation apparatus **140** may include one or more membrane distillation or pervaporation apparatuses, and distillation may include membrane distillation or pervaporation. The distillation apparatus **140** may receive the diluted draw stream **126** and produce distillate stream **142** (e.g., ethanol distillate) and draw permeate **144** (e.g., 10 gpm) stream. The distillate stream **142** can be directed (e.g., recirculated via one or more conduits and/or pumps) to the draw stream source **124**. The draw permeate **144** (e.g., still bottoms, such as water) stream can be removed from the system **400** via one or more conduits, valves, and/or pumps operably coupled to the distillation apparatus. In embodiments, the draw permeate **144** may be recycled in the system such as redirected to the diluted draw stream **126**, directed to waste, or one or more reverse osmosis elements. In examples, where the draw permeate **144** is directed to a reverse osmosis element, the reverse osmosis element may remove any residual solutes such as alcohol or glycerol form the draw permeate **144** and produce an RO permeate that is substantially pure water and an RO concentrate that includes the solutes. The RO permeate may be directed to waste such as a waste water outlet and the RO concentrate (e.g., alcohol and/or glycerol) can be directed back to the diluted draw stream **126**.
(55) In some examples, feed solution may be pressurized by a pump (e.g., feed stream source **114**) to form low-pressure feed stream **112** (e.g., 5% ABW, 12 gpm). The FO element **110** may receive low-pressure feed stream **112** and output concentrated feed stream **116** (e.g., 30 ABW at 2 gpm). Draw solution (e.g. at least about 30% ABW at 2 gpm) may be pressurized by a pump (e.g., draw stream source **124**) forming low-pressure draw stream **122**. The draw solution may include water and alcohol (e.g., ethanol). FO element **110** may receive low-pressure draw stream **122** and dispense diluted draw stream **126** (e.g., 5% ABW at 12 gpm). The distillation apparatus **140** (e.g., column or array of distillation columns) may receive diluted draw stream **126** and produce distillate stream **142** (e.g., ethanol distillate) and draw permeate **144** (e.g., reduced-ethanol permeate at 10 gpm). In some examples, portions of diluted draw stream **126** are received by the draw stream source **124** (e.g., a pump) in combination with distillate stream **142** (e.g., ethanol) to produce a draw solution of desired water and solute(s) (e.g., alcohol and dissolved sugar(s)) composition. In some embodiments, the output of the second side **125** is operably coupled to the downstream draw components **128**. The draw permeate **144** may be directed out of the system via the one or more downstream draw components **128**.
(56) In some embodiments, a regeneration apparatus can include at least one reverse osmosis (RO) element having at least one RO membrane therein. In some embodiments, the draw solution may be at least partially recovered (e.g., regenerated) by RO. FIG. **5** is a block diagram of a countercurrent FO system **500** for dewatering an alcohol solution, the system **500** including an RO element **150** for recovery of the draw solution via RO. The system **500** includes a feed stream source **114** configured to provide a feed stream **112** to an FO element **110**. The FO element **110** includes FO membrane **130** dividing a first side **115** from a second side **125** of the FO element **110**. The first side **115** can be operably coupled to one or more downstream product components as described herein. The second side **125** can be operably coupled to a draw stream source **124** configured to supply a draw stream **122** into the second side **125** of the FO element **110**. As the draw stream **122** is diluted in the FO element **110**, a diluted draw stream **126** is produced therefrom. The diluted draw stream **126** can be directed (e.g., via one or more conduits, pumps, valves, etc.) to the RO element **150**. The RO element **150** can include a housing containing an RO membrane **136** disposed therein. The housing (e.g., vessel or assembly) can be fluid tight and configured to hold the RO membrane **136** effective to at least partially define a first side **151** and second side **152** therein. The first side **151** and the second side **152** of the RO membrane can be at

least partially chemically separated by the RO membrane **136**, thereby defining two distinct volumes within the housing. The first side **151** and the second side **152** of the RO element **150** can be similar or analogous to the first side **115** and second side **125** of the FO element **110** described herein. The RO membrane **136** can include any membrane suitable for RO (e.g., a standard RO membrane or a low rejection RO membrane). For example, the RO membrane **136** may separate at least some water, alcohol or other permeable solutes, and impermeable solutes, from a solution having water, alcohol, and permeable and impermeable solutes therein. A single stage of RO may increase the ABW (or other permeable or impermeable solutes content) by as much as 5 wt %, such as about 1 wt % to about 3 wt %, or less than 3 wt %.

(57) The diluted draw stream **126** can be directed to the first side **151** of the RO element **150** where the RO membrane **136** separates at least some of the permeable solutes such as alcohol from the other solutes (e.g., (permeable and/or impermeable solutes such as glucose, fructose, glycerol, dissolved salts, etc.) and at least some of the water to form an RO concentrate in RO concentrate **154**. The RO concentrate may also be referred to as an RO reject herein. Such separation can be carried out in a stream or batch. The RO concentrate **154** may contain mostly water and permeable and impermeable solutes. For example, the RO concentrate **154** may contain at least some alcohol therein. At least some of the RO concentrate **154** can be directed back to the draw stream source **124**. In some embodiments, the RO concentrate **154** can be combined with one or more components of the draw solution to form (e.g., reform) the draw stream **122**. For example, the RO concentrate **154** can be combined with at least alcohol to regenerate draw stream **122**. The RO element **150** can also produce an RO permeate **156** from the second side **152** thereof. The RO permeate **156** can include water, alcohol, and one or more other permeable solutes therein. The RO permeate **156** can be further processed to regenerate (e.g., concentrate or more fully recover) at least some of the components thereof (e.g., one or both of permeable solutes or impermeable solutes) such as alcohol or glycerol, via distillation or further RO operations. In some embodiments, the RO permeate **156** can include or can be further processed to be substantially pure water. In some embodiments, one or more pumps (not shown) can be used to control pressure of the diluted draw stream **126** prior to entry into the RO element **150**.

(58) In some embodiments, the RO element(s) **150** can be configured as low rejection RO element(s) and/or spiral wound reverse osmosis element(s). In some examples, such as in low rejection RO elements, an element with reduced solute rejection may be used. Low rejection RO elements (e.g., RO elements having low rejection RO membranes) may be used to concentrate solutions with higher osmotic pressures than standard RO elements. In some embodiments, low rejection RO elements can be used to concentrate one or more impermeable solutes, such as sodium chloride, magnesium chloride, glycerol, sucrose, fructose, glucose, one or more dissolved salts, etc. The RO element(s) **150** may be configured as arrays of elements in parallel or in series. The elements or arrays of elements may be operated in a continuous system or in a batch system with buffer tanks.

(59) In some embodiments, an FO system for removing one or more components of a fluid mixture can include more than one draw stream regeneration apparatus. FIG. **6** is a block diagram of an FO system **600** configured for recovery of the draw solution by reverse osmosis and distillation. The system **600** can be configured as a countercurrent system as shown. The system **600** includes a feed stream source **114** configured to deliver a feed stream **112** to an FO element **110**. The FO element **110** includes an FO membrane **130** separating the first side **115** of the FO element **110** from the second side **125** of the FO element and is configured to selectively allow transport of one or more components from the feed stream **112** in first side **115** into the draw stream **122** in the second side **125**. The system **600** can include a draw stream source **124** operably coupled to and configured to provide the draw stream **122** to the second side **125**. The feed stream **112** is concentrated via FO as the draw stream **122** draws some of the components therefrom forming concentrated feed stream **116** (e.g., dewatered alcoholic solution). The concentrated feed stream **116** exits the first side **115**

and is directed to downstream product components (not shown).

(60) The draw stream **122** is diluted as one or more components of the feed stream **112** migrate across the FO membrane **130** to form diluted draw stream **126**. The diluted draw stream **126** can include one or more components (e.g., water) of the feed stream **112** as at least one diluent therein. The diluted draw stream **126** exits the second side **125** and is directed to one or more downstream draw components **128**. The one or more downstream draw components can include a pump configured to control pressure of the diluted draw stream **126**. The one or more downstream draw components **128** can be operably coupled to one or more regeneration apparatuses, such as at least one RO element **150**.

(61) The at least one RO element **150** can include an RO membrane **136** configured to separate one or more components of the diluted draw stream **126**. The first side **151** of the RO element **150** can include the diluted draw stream **126** which is converted to RO concentrate **154** therein via RO. The RO concentrate **154** can primarily include a mixture of water and impermeable solute(s). In some embodiments, the RO concentrate **154** can include at least some permeable solutes therein. At least a portion of the RO concentrate **154** can be directed to (e.g., recycled back to) the draw stream source **124**. The second side **152** includes an RO permeate **156** therein. The RO permeate **156** may primarily include a mixture of water and permeable solute(s) (e.g., ethanol). In some embodiments, the RO permeate **156** can include at least some impermeable solutes therein. The RO permeate **156** is directed to a distillation apparatus **140**.

(62) The distillation apparatus **140** can include one or more distillation columns. The RO permeate **156** is distilled in the distillation apparatus **140** effective to produce a distillate stream **142** which can be directed back to the draw stream source **124**. The distillate stream **142** can include predominantly one or more permeable concentrates (e.g., entirely alcohol) therein. The distillation apparatus **140** also produces a draw permeate **144** (e.g., still bottoms containing one or more permeable and/or impermeable solutes) which can be directed to one or more downstream components (not shown), such as waste storage or treatment, delivery apparatuses, or for further treatment. In some embodiments, the draw permeate **144** can include a permeate having a lower amount of alcohol than the distillate stream **142**, such as a reduced ethanol distillate or even substantially pure water.

(63) The distillate stream **142** (e.g., high alcohol content fluid) can be directed back to the draw stream source **124**. At least a portion of the distillate stream **142** can be combined with at least a portion of the RO concentrate **154** to form the draw stream **122**. One or more pumps can be disposed between any of the components of the system **600** to regulate pressure or speed of the fluids therein.

(64) In some examples, an alcoholic solution may be pressurized by a pump (e.g., feed stream source **114**) to form low-pressure feed stream **112** (e.g., about 5% ABW at 12 gpm). FO element **110** receives the low-pressure feed stream **112** and dispenses concentrated feed stream **116** (e.g., 30% ABW at 2 gpm). Draw solution (e.g. 30% ABW at 2 gpm) may be pressurized by a pump (e.g., draw stream source **124**) forming low-pressure draw stream **122**. The draw solution includes a mixture of water, permeable solute(s) (e.g., ethanol), and impermeable solute(s) (e.g., glucose, fructose, glycerol, sodium chloride, magnesium chloride, other dissolved salts, etc.). The FO element **110** receives low-pressure draw stream **122** and dispenses diluted draw stream **126** (e.g., 5% ABW at 12 gpm). A downstream draw component **128**, such as a pump receives diluted draw stream **126** and produces high-pressure diluted draw stream **126** (e.g., 500-800 psi). At least one RO element **150** receives high-pressure diluted draw stream **126** and dispenses RO concentrate **154** (e.g., an RO reject stream) and RO permeate **156**. RO concentrate **154** may be a mixture of water and impermeable solute(s) such as glycerol. At least some permeable solute(s) such as ethanol may be present in the RO concentrate **154**. RO permeate **156** may be a mixture of water and permeable solute (e.g., ethanol). Distillation apparatus **140** receives RO permeate **156** and produces ethanol distillate in the distillate stream **142**, and also produces reduced-ethanol permeate in the draw

permeate **144**. The ethanol distillate stream **142** may be plumbed to the RO concentrate **154** to reform draw stream **122**. In some examples, distillation of the RO permeate **156** may be used. In other examples, distillation of the diluted draw stream **126** to produce a diluted draw solution with reduced alcohol, followed by RO to concentrate additional permeable and impermeable solute(s) may be used. Accordingly, in some embodiments, the distillation apparatus **140** can be disposed "upstream" from the RO element **150**.

(65) In some embodiments, the draw permeate **144** exiting the distillation apparatus **140** may include at least some permeable solute (e.g., ethanol) therein, such as 2 wt % or less (e.g., 1 wt % or less) of the draw permeate **144**. At least an additional or second RO element **150***b* may be operably coupled to the distillation apparatus **140** and may be configured to receive the draw permeate **144**. For example, the at least a second RO element **150***b* may be located downstream from the at least one distillation apparatus **140** on the draw permeate **144** side thereof. The at least a second RO element **150***b* may remove (e.g., polish) any remaining solutes (e.g., alcohol) from the draw permeate **144** (e.g., bottoms) exiting the distillation apparatus **140**. For example, the RO element **150** may remove most of the glycerin from the diluted draw stream **126**, the distillation apparatus **140** may remove most of the ethanol from the RO permeate **156**, and the at least a second RO element **150***b* may remove any residual solutes (e.g., ethanol, VOCs, and/or glycerin) from the draw permeate **144**, to provide substantially pure water stream and as solute stream. For example, the draw permeate **144** may be 2% ABW or less (e.g., less than 1% ABW or less than 0.5 wt % ABW) after distillation and the at least a second RO element **150***b* may remove substantially all of the alcohol therefrom. The RO permeate **156***b* (e.g., substantially pure water) may be removed from the system **600** such as directed to a waste outlet (e.g., drain or gray water supply) or may be directed back to the feed side of the system **600** prior to the FO element **110**. The RO concentrate **154***b* (e.g., alcohol) may be recirculated back to distillation apparatus **140**, such as by combining the (second) RO concentrate **154***b* with the (first) RO permeate **156** prior to introducing the RO concentrate **154** into the distillation apparatus **140**. Accordingly, the draw permeate **144** may be further polished to recover any residual permeable solutes therefrom. The distillation apparatus **140** may be used to recover (e.g., distill) the residual permeable solutes and recycle the same for use in the draw stream or provide a substantially pure permeable solute stream (e.g., ethanol waste stream).

(66) The countercurrent FO system **600** may be arranged and operated to remove a selected amount of permeable solute(s) from the feed stream or at a selected rate. For example, the draw stream flow rate may be relatively high (e.g., at least 10 times higher or faster) compared to the feed stream flow rate in order to remove a selected amount of permeable solute(s) from the feed stream in the FO membrane or at a selected rate. Such countercurrent flow configurations may allow for the removal of a selected amount of permeable solute from the feed stream by the time the feed stream exits the FO element **110** and maintaining a relatively low permeable solute content in the draw stream throughout the FO element **110**. In examples, the flow rate of one or more of the draw stream or the feed stream may be selected to provide a selected amount of permeate flow into the draw stream (in the FO element). For example, the flow rate of the draw stream may be relatively high to limit the permeate flow rate from the feed stream to the draw stream to one tenth of the flow rate of the draw stream or less (e.g., 10%, 8%, 5%, 3%, 1%, or ranges between any of the foregoing). Put another way, the flow rate of the draw stream may be selected to limit amount of the permeate flow from the feed stream to the draw stream to one tenth of the volume of the draw stream or less (e.g., 10%, 8%, 5%, 3%, 1%, or ranges between any of the foregoing) per unit volume of the draw stream present in the FO element **110**. Such countercurrent configurations and flow rates may keep the permeable solute (e.g., permeate) content as low as possible in the draw solution despite having received the permeable solute from the feed solution.

(67) In some embodiments, multiple RO elements can be used to provide step wise regeneration of a draw solution. FIG. **7** is a block diagram of an FO system **700** for dewatering an alcoholic

solution. The system **700** includes one or more components configured for recovery of the draw solution by low rejection RO, reverse osmosis, and distillation. The system includes a feed stream source **114** configured to deliver a feed stream **112** to the FO element **110**. The FO element includes a first side **115**, second side **125**, and FO membrane **130** therein. The feed stream **112** is concentrated in the FO element to produce concentrated feed stream **116** as disclosed herein. The system **700** includes a draw stream source **124** configured to provide draw stream **122** into the FO element **110**. As the draw stream **122** travels through the FO element **110**, the draw stream **122** is diluted to form diluted draw stream **126**. Diluted draw stream **126** is directed through a plurality of draw stream regeneration apparatuses via one or more downstream draw components **128**.

(68) The diluted draw stream **126** is initially directed to a first RO element **150***a* where a first RO concentrate **154***a* is formed. The first RO element **150***a* can be configured as a low rejection RO element, that is, an RO element that having a low rejection RO membrane which has a relatively high flux and low rejection rate (e.g., relative to a standard RO element with greater than 99% impermeable solute rejection). For example, a low rejection RO membrane **136***a* may have a rejection rate of 50% of impermeable solutes and can promote a flux therethrough at least 50% higher than a standard RO membrane **136***b* at a given hydrostatic pressure. The low rejection rate of the low rejection RO element may allow the concentration of solutions with impermeable solute species concentrations at osmotic pressures exceeding the hydrostatic limit (e.g., 1000 psi) by allowing impermeable solute species through the membrane, thereby reducing the concentration difference across the membrane. In some embodiments, low rejection RO membranes **136***a* and elements having the same may have a solute rejection rate between about 20 to about 80 percent, such as about 30 to about 70 percent, or about 40 to about 60 percent. The first RO concentrate **154***a* can have a higher concentration of one or more components of the draw stream **122** than the diluted draw stream **126**. For example, the first RO concentrate **154***a* can include a mixture of alcohol and water having a higher concentration of alcohol and/or other solutes than the diluted draw stream **126**. The RO concentrate **154***a* is directed back (e.g., recycled) to the draw stream source **124**, such as via one or more conduits, valves, or pumps. The first RO element **150***a* produces a first RO permeate **156***a* which is primarily a mixture of water, impermeable solute, and alcohol. The concentration of impermeable solute(s) in the first RO permeate **156***a* is lower than in the diluted draw stream **126**. The first RO permeate **156***a* can be directed to a second RO element **150***b* via one or more downstream draw components **128***b* (e.g., a pressurized pump).

(69) The second RO element **150***b* can be configured as a standard RO element, that is, an RO element including an RO membrane **136***b* having a lower flux and higher rejection rate than the low rejection RO membrane **136***a*. As the first RO permeate **156***a* travels through the second RO element **150***b*, a second RO concentrate **154***b* and second RO permeate **156***b* are produced. The second RO concentrate **154***b* can primarily include one or more concentrated impermeable solutes (e.g., dissolved salts, glucose, fructose, at least some alcohol, etc.) and water, while the second RO permeate **156***b* can include primarily a mixture of alcohol and water. The second RO concentrate **154***b* is directed back to the draw stream source **124** via one or more conduits, pumps, valves, etc. The second RO permeate **156***b* is directed to distillation apparatus **140**. Distillation apparatus **140** can receive the second RO permeate **156***b* and distill the same to produce distillate stream **142** and draw permeate **144** (e.g., RO permeate still bottoms). The distillate stream **142** can include primarily alcohol (e.g., concentrated alcohol) and the draw permeate **144** can include water and alcohol, such as in a highly diluted ethanol solution. The distillate stream **142** can be directed to the draw stream source **124**. The distillation apparatus **140** can be plumbed to the draw stream source **124** via one or more conduits. At least some of the distillate stream **142** can be combined with one or more of at least some of the first RO concentrate **154***a* or at least some of the second RO concentrate **154***b* to reconstitute (e.g., regenerate) the draw solution or draw stream **122**.

(70) In some examples, an alcoholic beverage feed solution may be pressurized by a pump to form low-pressure feed stream **112** (e.g., 5 ABW at 12 gpm). The FO element **110** (or array of elements)

may receive low-pressure feed stream **112** and dispense concentrated feed stream **116** (e.g., 30% ABW at 2 gpm). Draw solution (e.g., 30% ABW at 2 gpm) may be pressurized by a pump (e.g., draw stream source **124**) to form low-pressure draw stream **122**. The draw solution may be a mixture of water, permeable solutes such as ethanol, and impermeable solute(s) such as glycerol. The draw solution can be composed to have a higher concentration of one or more components of the alcoholic beverage feed solution to cause the feed solution to at least partially retain the one or more components therein. FO element **110** may receive low-pressure draw stream **122** and dispense diluted draw stream **126** (e.g., 5% ABW at 12 gpm). The diluted draw stream **126** can be routed through a pump (e.g., downstream draw component **128***a*) to produce high-pressure diluted draw stream **126** (e.g., about 800 psi). The (low rejection) first RO element **150***a* receives the high-pressure diluted draw stream **126** and dispenses a mixture of water and impermeable solute(s) (the first RO concentrate **154***a*) at a higher concentration than in the diluted draw stream **126** and may include an alcohol (e.g., ethanol) at a similar concentration (e.g., within about 5% ABW) to the diluted draw stream **126**. The (low rejection) first RO element **150***a* may also dispense a mixture of water, impermeable solute(s), and ethanol (e.g., first RO permeate **156***a*); the impermeable solute(s) being present at a lower concentration than in the diluted draw stream **126**. The (low rejection) first RO element **150***a* may produce ethanol at a similar concentration to the diluted draw stream **126** in the first RO permeate. In some examples, the ethanol concentration may be similar (e.g., less than about 5% ABW, such as about 1% ABW) in the feed stream, RO concentrate stream, and RO permeate stream of the (low rejection) first RO element. In some examples, negative rejection (e.g., increased permeation of ethanol) may change the concentration in the RO concentrate stream and RO permeate stream by as much as 5% ABW each.
(71) The first RO permeate **156***a* is directed through a pump (e.g., downstream draw component **128***b*) to produce high pressure RO permeate **156***a*. The second RO element **150***b* receives the high pressure RO permeate **156***a* and produces a second RO concentrate **154***b* and a second RO permeate **156***b*. The second RO concentrate **154***b* is primarily concentrated impermeable solute(s), permeable solute(s) (e.g., ethanol) and water. The second RO permeate **156***b* is primarily a mixture of permeable solute(s) in solvent (e.g., ethanol in water). The second RO permeate stream is directed to a distillation column (e.g., distillation apparatus **140**. The distillation column produces concentrated ethanol (e.g., distillate stream **142**) and a very diluted ethanol stream (e.g., draw permeate **144**). The distillate stream **142** may be plumbed to combine with the second RO concentrate **154***b* to form a pre-draw stream comprising both the distillate stream **142** and RO concentrate **154***b*. Pre-draw stream may be plumbed to combine with and the first RO concentrate **154***a* to form draw stream **122**.
(72) In some embodiments, the draw solution can be recovered using a plurality of RO elements. For example, the draw solution or draw stream **122** may be recovered by a first RO stage and a second RO stage. The RO elements in the first and second (recovery) stages may be the same, or may be different, providing different levels of rejection of solutes. In an example, an FO system can include a brackish water RO element in the first stage and a seawater RO element in the second stage. In some embodiments, an FO system can include a low rejection RO element in conjunction with (e.g., prior to) the first and second RO elements.
(73) FIG. **8** is a block diagram of an FO system **800** for dewatering an alcoholic solution and configured for recovery of a draw solution via multiple reverse osmosis operations. The FO system **800** for dewatering an alcoholic solution is configured for recovery of a draw solution via low rejection RO element **150***a*, a first reverse RO element **150***b*, and a second RO element **150***c*. The system **800** includes a feed stream source **114** configured to deliver a feed stream **112** to the FO element **110**. The FO element includes a first side **115**, second side **125**, and FO membrane **130** separating the first side **115** from the second side **125**. The feed stream **112** is concentrated in the FO element to produce concentrated feed stream **116** as disclosed herein. The system **800** includes a draw stream source **124** configured to provide draw stream **122** into the FO element **110**. As the

draw stream **122** travels through the FO element **110**, the draw stream **122** is diluted to form diluted draw stream **126**. Diluted draw stream **126** is directed through a plurality of draw stream regeneration apparatuses via one or more downstream draw components **128**.

(74) The diluted draw stream is directed through a low rejection RO element **150***a*. The diluted draw stream **126** is processed in the low rejection RO element **150***a* to produce a first RO concentrate **154***a* having a higher concentration of impermeable solutes than the diluted draw stream **126**; and to produce a first RO permeate **156***a*. The first RO concentrate **154***a* includes water, impermeable solute(s), and at least some permeable solutes (e.g., alcohol). In some embodiments, the concentration of alcohol in the first RO permeate **156***a* a may be similar to the concentration of alcohol in the diluted draw stream **126** and the first RO concentrate **154***a*. In some embodiments, the concentration of impermeable solutes may be higher in the first RO concentrate **154***a* than in the diluted draw stream **126**. The first RO permeate **156***a* may include water, at least some alcohol, and at least some impermeable solute(s). The first RO permeate **156***a* may have a lower concentration of alcohol and/or impermeable solute(s) than the diluted draw stream **126**. The first RO concentrate **154***a* is directed back to the draw stream source **124** and the first RO permeate is directed to second RO element **150***b* via the one or more downstream draw components **128***b* (e.g., one or more conduits and a pump).

(75) The first RO permeate **156***a* is processed in the first RO element **150***b* by RO to produce a second RO concentrate **154***b* and a second RO permeate **156***b*. The second RO concentrate **154***b* may have a higher concentration of impermeable solutes than the first RO permeate **156***a*. The second RO concentrate is directed to the draw stream source **124** via one or more conduits, valves, pumps, etc. The second RO permeate **156***b* primarily includes water, at least some alcohol, and at least some impermeable solute(s). The second RO permeate **156***b* may have a lower concentration of alcohol and impermeable solute(s) than the first RO permeate **156***a*. The second RO permeate **156***b* is directed to a second RO element **150***c* via one or more downstream draw component **128***c* (e.g., one or more conduits, pumps, valves, etc.)

(76) The second RO permeate **156***b* is processed in the second RO element **150***c* by RO to produce a third RO concentrate **154***c* and a third RO permeate **156***c*. The third RO concentrate **154***c* may have a higher concentration of alcohol and/or impermeable solutes than the second RO permeate **156***b*. In some embodiments, the third RO concentrate **154***c* includes one or more concentrated permeable solutes such as alcohol (e.g., ethanol). The third RO concentrate **154***c* is directed to the draw stream source **124** via one or more conduits, valves, pumps, etc. The third RO permeate **156***c* primarily includes one or more of water, at least some alcohol, or at least some impermeable solute(s). The third RO permeate **156***c* may have a lower concentration of alcohol (and other permeable solutes) and impermeable solute(s) than the second RO permeate **156***b*. In some embodiments, the third RO permeate **156***c* can include substantially pure water. The third RO permeate **156***c* is directed to out of the system **800** or may be further processed by additional downstream components (not shown), including conduits, pumps compressors, distillation apparatuses, RO elements, etc.

(77) The third RO concentrate **154***c* can be combined with the second RO concentrate **154***b* at a point intermediate to the draw stream source **124** and the first and second RO elements **150***b* and **150***c*. The combined second and third RO concentrates **154***b* and **154***c* can be combined with the first RO concentrate **154***a* to reform (e.g., form a reconstituted or regenerated) draw stream **122**. The combined second and third RO concentrates **154***b* and **154***c* can be combined with the first RO concentrate **154***a* at a point intermediate to the draw stream source **124** and the low rejection RO element **150***a*.

(78) In some embodiments, the order of any of the RO elements may vary. For example, diluted draw stream **126** can be concentrated by a first RO element followed by a low rejection RO element and the second RO element. In some examples, the low rejection RO and the reverse osmosis may be staged in any order. In some embodiments, the systems herein can be arranged to

recover one or more specific impermeable or permeable solutes prior to recovering on or more additional permeable or impermeable solutes. For example, regeneration apparatuses can be arranged to recover glycerol from a diluted draw stream prior to recovering ethanol therefrom.
(79) In some examples, an alcoholic beverage feed solution (e.g., beer) may be pressurized by a pump to form low-pressure feed stream **112** (e.g., about 5% ABW at 12 gpm). The FO element **110** receives low-pressure feed stream **112** and dispenses concentrated feed stream **116** (e.g., 30% ABW at 2 gpm). Draw solution (e.g., 30% ABW) may be pressurized by a pump forming low-pressure draw stream **122**. The draw solution may be a mixture of water, ethanol, and impermeable solute(s). FO element **110** may receive low-pressure draw stream **122** and dispense diluted draw stream **126**. A pump may receive diluted draw stream **126** and produce high-pressure diluted draw stream **126** (e.g., about 500 to about 1000 psi). The low rejection RO element **150***a* receives the high-pressure diluted draw stream **126** and dispenses the first RO concentrate **154***a* primarily including impermeable solute(s) at a higher concentration than in the diluted draw stream **126**, at least some water, and may include at least some ethanol. The low rejection RO element **150***a* also dispenses the first RO permeate **156***a* primarily including water, ethanol, and impermeable solute(s) having a concentration lower than the concentration of impermeable solute(s) in the diluted draw stream **126** and the RO concentrate **154***a*.
(80) The first RO permeate can be routed through a pump to produce high pressure in the first RO permeate **156***a*. A first RO element **150***b* (as differentiated from to the low rejection RO element) receives the high pressure first RO permeate **156***b* and produces a second RO concentrate **154***b* and a second RO permeate **156***b*. The second RO concentrate **154***b* may include at least some water, impermeable solute(s) at a concentration higher than in first RO permeate **156***a*, and at least some ethanol. The second RO permeate **156***b* may include a mixture of alcohol (e.g., ethanol) in water at a concentration lower than the first RO permeate **156***a*.
(81) The second RO permeate **156***b* can be routed through a pump to produce high pressure (e.g., 800 psi) in the second RO permeate **156***b*. A second RO element **150***c* is configured to receive the high pressure second RO permeate **156***b* and produce third RO permeate **156***c* and third RO concentrate **154***c*. The third RO permeate **156***c* may include highly diluted ethanol in water. The third RO concentrate **154***c* may include concentrated ethanol (and/or impermeable solutes) in water at concentration higher than in second RO permeate **156***b*. The third RO concentrate **154***c* may be plumbed to combine with second RO concentrate **154***b* to form a pre-draw stream. The pre-draw stream may be plumbed to combine with first RO concentrate **154***a* to reform draw stream **122**. Additional RO stages may be added to increase the total ethanol (other permeable solute or impermeable solute) recovery as needed.
(82) In some embodiments, one or more permeable solutes and one or more substantially impermeable solutes can be recovered or regenerated from a diluted draw solution separately (e.g., a predominant recovered permeable solute is a specific species) in a system. For example, a first permeable solute may be recovered in a first recovery apparatus (or array thereof) and at least a second impermeable solute may be recovered by at least a second recovery apparatus (or array thereof). After separately recovering the permeable solutes, at least some of the first and second solutes can be admixed with or recombined to form a recovered/regenerated draw solution.
(83) FIG. **9** is a block diagram of an FO system **900** for dewatering a solution and recovery of a draw solution via multiple reverse osmosis operations. The system **900** includes a first array of RO elements arranged to recover a first impermeable solute (e.g., glycerol) from a diluted draw solution and a second array of RO elements arranged to recover a first permeable solute (e.g., ethanol) from the diluted draw solution. The arrays of RO elements can be arranged in parallel, in series, or any combination(s) thereof.
(84) The system **900** includes an FO element **110** as disclosed herein. The feed stream **112** and a draw stream **122** are fed into the FO element **110**, such as in countercurrent operation as shown. The draw stream **122** includes a higher concentration of one or more permeable solutes than the

feed stream **112** and/or concentrated feed stream **116**, and may include additional impermeable solutes (such as in solutions where the sum of the permeable and impermeable solutes collectively provide a greater osmotic pressure in the draw stream than the solute(s) in the feed stream). The FO element **110** outputs a concentrated feed stream **116** having a higher concentration of one or more permeable solutes (e.g., ethanol) than the feed stream **112**. The FO element **110** also outputs a diluted draw stream **126** having a lower concentration of at least one species of the one or more permeable solutes (e.g., ethanol) and of the one or more impermeable solutes (e.g. glycerol) than the draw stream **122** due to at least some solvent (e.g., water) crossing the FO membrane. The total amounts of permeable solutes and impermeable solutes in the draw stream may remain essentially static (ignoring some negligible amounts of loss or gain) while the concentration(s) of each are lowered due to dilution by the solvent (water) crossing the FO membrane. The diluted draw stream **126** can be directed to one or more draw solution regeneration apparatuses each configured to regenerate (e.g., concentrate or recover) at least one draw solute from the diluted draw stream **126**. The one or more draw solution regeneration apparatuses can include any of the RO elements, distillation apparatuses, or other regeneration apparatuses disclosed herein.

(85) The one or more draw solution regeneration apparatuses may include a first plurality of RO elements **150*a*-150*c*** and at least a second plurality of RO elements **150*d*-150*h***. The first plurality of RO elements may primarily separate a first solute (e.g., impermeable solute) such as glycerol from the diluted draw stream **126** (e.g., selectively isolate one or more major species while additionally isolating minor amounts of additional species), and the at least a second plurality of RO elements **150*d*-150*h*** may primarily separate at least a second solute (e.g., permeable solute) such as ethanol from the diluted draw stream **126**. As the diluted draw solution (to be regenerated) passes through the array (e.g., series) of RO elements one or more solutes therein can be steadily concentrated until a desired concentration is reached.

(86) In some examples, a first RO element **150*a*** can be fluidly coupled to the FO element **110**. The first RO element **150*a*** can receive the diluted draw stream **126** and output an RO concentrate **154*a*** and an RO permeate **156*a*** (e.g., in a streams or batches). The first RO concentrate **154*a*** can include a mixture of at least a first impermeable solute (e.g., a plurality of impermeable solutes) and a first permeable solute and water having a higher concentration of at least the first impermeable solute and/or other impermeable solutes than the diluted draw stream **126**. The concentration of the first impermeable solute in the first RO permeate **156*a*** may be lower than in the diluted draw stream **126** and/or the first RO concentrate **154*a***. The first RO concentrate **154*a*** can be directed to a second RO element **150*b*** and the first RO permeate can be directed to a third RO element **150*c***.

(87) The second RO element **150*b*** is fluidly coupled to the first RO element **150*a***. The first RO concentrate **154*a*** is received by the second RO element **150*b*** and is at least partially separated (e.g., filtered) therein. The second RO element **150*b*** outputs a second RO concentrate **154*b*** and a second RO permeate **156*b***. The second RO concentrate **154*b*** can include a mixture of at least the first impermeable solute (e.g., a plurality of impermeable solutes) and the first permeable solute (e.g. alcohol) and water having a higher concentration of at least the first impermeable solute and/or other impermeable solutes and alcohol than the diluted draw stream **126** and the first RO concentrate **154*a***. The concentration of the first impermeable solute in the second RO permeate **156*b*** may be lower than in one or more of the diluted draw stream **126**, the first RO concentrate **154*a***, and/or the second RO concentrate **154*b***. The second RO concentrate **154*b*** may include a greater amount of the first impermeable solute (e.g., glycerol) than any of the other RO concentrates in the system **900**. The second RO concentrate **154*b*** can be directed back to the FO element **110** (or a downstream apparatus intermediate the second RO element **150*b*** and the FO element **110**) and the second RO permeate can be directed back to the first RO element **150*a*** (e.g., recycled therethrough). The second RO concentrate **154*b*** can be combined with one or more additional solutions (e.g., additional concentrate streams) at a point C intermediate to the FO element **110**.

(88) In some examples of the system **900**, the second RO element **150***b* can be a low rejection RO membrane, which can be operated at a higher osmotic pressure than a standard RO membrane (e.g., membrane that is less permeable, having higher rejection rates than the low rejection RO membranes). The low rejection RO membrane can be operated at a high pressure which may concentrate the one or more impermeable solutes (e.g., glycerol) in the solution therein at a higher rate than in a standard RO system. In some examples, the second RO element **150***b* can include a plurality of RO elements (e.g., an array of RO elements arranged in series and/or in parallel) and the RO concentrate **154***a* may be cycled through each of the plurality of RO elements progressively concentrating at least the first impermeable solute therein upon each successive RO operation. In such examples, the plurality of RO elements in the position of the second RO element **150***b* can include at least 2 RO elements, such as 20 to 100, 2 to 50, 5 to 40, 10 to 30, 2 to 20, 15 to 25, 30 to 50, 2 to 10, 3 to 8, 2 to 5, 3 to 6, or 5 to 10, more than 10, more than 20, more than 30, less than 50, less than 40, less than 30, less than 20, or less than 10 RO elements.
(89) In some examples, the system **900** includes an additional, third RO element **150***c* to further remove at least the first impermeable solute from the diluted draw stream (as it is found after at least two RO operations). In such examples, the third RO element **150***c* can ensure that at least a major portion of one or more undesirable impermeable or permeable solutes (e.g., species of impermeable or permeable solutes that interfere with further regeneration or recovery of other solutes) are isolated or recovered from the in-process solution (e.g., solution being processed for recovery of further, different solutes) such that further regeneration/recovery of the draw solution progresses without interference therefrom. The third RO element **150***c* is fluidly coupled to the second RO element **150***b* and receives the second RO permeate **156***b* which is at least partially separated therein. The third RO element **150***c* outputs a third RO concentrate **154***c* and a third RO permeate **156***c*. The third RO concentrate **154***c* can include a mixture of at least the first impermeable solute (e.g., a plurality of impermeable solutes) and water having a higher concentration of at least the first impermeable solute (e.g., glycerol) and/or permeable solutes than the diluted draw stream **126**, the diluted draw stream **126**, or the first RO permeate **156***a*. In some embodiments, the third RO concentrate **154***c* can include a mixture of at least the first permeable solute and water having a concentration similar to the diluted draw stream **126** and the second RO permeate **156***b*. The third RO element **150***c* and operation can essentially to ensure that essentially no undesirable impermeable solutes are present when the third RO permeate **156***c* is further subjected to recovery of at least a first permeable solute (e.g., ethanol). The third RO concentrate **154***c* may be directed back to the first RO element **150***a* for further solute recovery therein (e.g., recycled therethrough). The third RO concentrate **154***c* can be combined with diluted draw stream **126** at point A (e.g., one or more of a valve, a pipeline, a tank, etc.) and the combined diluted draw stream **126** and third RO concentrate **154***c* can be further combined with the second RO permeate **156***b* at point B (e.g., one or more of a valve, a pipeline, a tank, etc.) prior to entering the first RO element **150***a*.
(90) The concentration of the first impermeable solute in the third RO permeate **156***c* may be lower than in one or more of the diluted draw stream **126**, the first RO concentrate **154***a*, and/or the second RO concentrate **154***b*, such as negligible amounts of the first impermeable solute (e.g., amounts that do not interfere with further recovery/regeneration operations). For example, the third RO permeate **156***c* can include less than about 2 wt % of the first impermeable solute, such as about 0.1 wt % to about 2 wt %, or greater than 0 wt % to about 1 wt % of the first impermeable solute. The concentration of at least the first permeable solute (e.g., ethanol) can be substantially constant throughout the RO elements **150***a*-**150***c*. In some examples, the concentration of one or more permeable solutes (e.g., ethanol) can remain steady, such as by varying by less than 5 wt % between each RO element or operation, such as by less than about 3 wt %, less than about 2 wt %, or about 1 wt % to about 3 wt % between at least two of the RO elements **150***a*-**150***c*.
(91) The third RO permeate **156***c* can be directed through a second set of draw stream regeneration

apparatuses. Each of the second set of draw stream regeneration apparatuses may recover (e.g., concentrate) at least the first permeable solute (e.g., ethanol) therefrom (e.g., regenerate at least a portion of the draw solution). For example, the third RO permeate **156***c* can be directed to a fourth RO element **150***d*, where one or more permeable solutes are recovered. The fourth RO element **150***d* can be fluidly coupled to the third RO element **150***c*.

(92) The fourth RO element **150***d* outputs a fourth RO concentrate **154***d* and a fourth RO permeate **156***d*. The fourth RO concentrate **154***d* can include a mixture of at least the first permeable solute (e.g., a plurality of permeable solutes which can also include residual amounts of the impermeable solute(s)) and water having a higher concentration of at least the first permeable solute and/or other permeable solutes than the diluted draw stream **126** and the third RO permeate **156***c*. The concentration of the first permeable solute (e.g., ethanol) in the fourth RO permeate **156***d* may be lower than in fourth RO concentrate **154***d* or the third RO permeate **156***c*. The substantial lack of the first impermeable solute (e.g., glycerol) in the third RO permeate **156***c* may allow for a more straightforward recovery process for at least the first permeable solute (e.g., undesirable chemical interactions between the first permeable solute and the RO membrane and/or chemical components if the feed and draw solutions are absent). The fourth RO concentrate **154***d* may include a greater amount of at least the first permeable solute than the third RO permeate **156***c*. The fourth RO concentrate **154***d* can be directed to a fifth RO element **150***e* and the fourth RO permeate **156***d* can be directed to a seventh RO element **150***g*.

(93) The fifth RO element **150***e* can be fluidly coupled to the fourth RO element **150***d* and can receive the RO concentrate **154***d* and at least partially separate (e.g., filter) at least some of the components therein. The fifth RO element **150***e* outputs a fifth RO concentrate **154***e* and a fifth RO permeate **156***e*. The fifth RO concentrate **154***e* can include a mixture of at least the first permeable solute (e.g., a plurality of permeable solutes that may include residual amounts of the first impermeable solute) and water having a higher concentration of at least the first permeable solute and/or other permeable solutes than the diluted draw stream **126**, the fourth RO concentrate **154***d*, and the fourth RO permeate **156***d*. The concentration of the first permeable solute (e.g., ethanol) in the fifth RO permeate **156***e* may be lower than in fifth RO concentrate **154***e* or the fourth RO concentrate **154***d*. The fifth RO concentrate **154***e* can be directed to a sixth RO element **150***f* and the fifth RO permeate **156***e* can be directed back to the fourth RO element **150***d*.

(94) In some examples, the fifth RO element **150***e* can include a plurality of RO elements (e.g., at least two RO elements arranged in parallel and/or in series) to progressively concentrate at least the first permeable solute (e.g., ethanol) to a desired concentration prior to reaching the sixth RO element **150***f*. In such examples, the plurality of RO elements in position of the fifth RO element **150***d* can include at least 2 RO elements, such as 2 to 100, 2 to 50, 5 to 40, 10 to 30, 2 to 20, 15 to 35, 20 to 40, 30 to 50, 35 to 45, 2 to 10, 3 to 8, 2 to 5, 3 to 6, or 5 to 10, more than 10, more than 20, more than 30, less than 50, less than 40, less than 30, less than 20, or less than 10 RO elements.

(95) The output of the fifth RO element **150***e* is fluidly coupled to at least the sixth RO element **150***f* and the fourth RO element **150***d* (e.g., at least the second side of the fifth RO element **150***e* is fluidly coupled to feed the first side of the fourth RO element **150***d* to recycle the fifth RO permeate **156***e* through the fourth RO element **150***d*). The fifth RO permeate **156***e* can be combined with at least the third RO permeate **156***c* at a point D prior to the fourth RO element **150***d*.

(96) The fifth RO concentrate **154***e* is received and at least partially separated by the sixth RO element **150***f*. The sixth RO element **150***f* outputs a sixth RO concentrate **154***f* and a sixth RO permeate **156***f*. The sixth RO concentrate **154***f* can include a mixture of at least the first permeable solute (e.g., a plurality of permeable solutes that may include residual amounts of the first impermeable solute) and water having a higher concentration of at least the first permeable solute and/or other permeable solutes than the diluted draw stream **126**, the fifth RO concentrate **154***e*, the fifth RO permeate **156***e*, and the sixth RO permeate **156***f*. The sixth RO concentrate **154***f* may include a greater concentration of at least the first permeable solute than any other concentrate or

permeate in the system **900**. The concentration of the first permeable solute (e.g., ethanol) in the sixth RO permeate **156***f* may be lower than in the sixth RO concentrate **154***f* or the fifth RO concentrate **154***e*. The sixth RO concentrate **154***f* can be directed back to the FO element **110** to at least partially reconstitute the draw stream **122** and the sixth RO permeate **156***f* can be directed back to the fifth RO element **150***e* (e.g., for further RO operations).
(97) The sixth RO concentrate **154***f*, having the highest concentration of at least the first permeable solute (e.g., ethanol) in the system **900** can be combined with the third RO concentrate **154***c* having the highest concentration of at least the first impermeable solute (e.g., glycerol) in the system **900** at point C prior to the FO element **110**. The combination of the two RO concentrates **154***c* and **154***f* can at least partially reconstitute (e.g., regenerate) the draw stream **122**, such that the solute(s) concentration(s) (e.g., permeable and impermeable solutes) therein is near or identical to the concentration(s) in the draw stream **122** prior to FO treatment.
(98) The sixth RO permeate **156***f* is directed back to the first side of the fifth RO element **150***e*, where it undergoes additional RO operation(s) to further remove the first permeable solute therefrom. The sixth RO permeate **156***f* can be combined with the fourth RO concentrate **154***d* at a point E prior to the fifth RO element **150***e*.
(99) Returning to the fourth RO permeate **156***d* stream, the output of the second side of the fourth RO element **150***d* is fluidly coupled to the first side of the seventh RO element. The fourth RO permeate **156***d* enters the seventh RO element **150***g* where one or more components therein are separated. The seventh RO element **150***g* outputs a seventh RO concentrate **154***g* and a seventh RO permeate **156***g*. The seventh RO concentrate **154***g* can include a mixture of at least the first permeable solute and water having a higher concentration of at least the first permeable solute and/or other permeable solutes than an eighth RO concentrate **154***h* and eighth RO permeate **156***h* (and in some examples may be substantially equal (e.g., within about 1-2% ABW) to the concentration in the fourth RO permeate **156***d*). The concentration of the first permeable solute (e.g., ethanol) in the seventh RO permeate **156***g* may be lower than the concentration in fourth RO permeate **156***d* and/or the seventh RO concentrate **154***g*.
(100) The seventh RO concentrate **154***g* can be directed back to the fourth RO element **150***d* for further RO operations and the seventh RO permeate **156***g* can be directed to an eighth RO element **150***g*. The seventh RO concentrate **154***g* can be combined with one or more of the third RO permeate **156***c* and the fifth RO permeate **156***e* at point D. The seventh RO permeate is directed to the eighth RO element **150***h*.
(101) In some examples, the seventh RO element **150***g* can include a plurality of RO elements (e.g., at least two RO elements arranged in series and/or in parallel) to progressively concentrate at least the first permeable solute to a desired concentration prior to recycling back to the fourth RO element **150***d*. In such examples, the plurality of RO elements in position of the seventh RO element **150***g* can include at least 2 RO elements, such as 2 to 100, 2 to 50, 5 to 40, 10 to 30, 2 to 10, 3 to 8, 2 to 5, 3 to 6, or 5 to 10, more than 10, more than 20, more than 30, less than 50, or less than 10 RO elements.
(102) The seventh RO concentrate **154***g* can be directed back to the fourth RO element **150***d* for further RO operations and the seventh RO permeate **156***g* can be directed to an eighth RO element **150***g*. The seventh RO concentrate **154***g* can be combined with one or more of the third RO permeate **156***c* and the fifth RO permeate **156***e* at point D. The seventh RO permeate is received at the eighth RO element **150***h* where one or more components therein are at least partially separated.
(103) The eighth RO element **150***h* outputs an eighth RO concentrate **154***h* and an eighth RO permeate **156***h*. The eighth RO concentrate **154***h* can include a mixture of at least the first permeable solute and water having a higher concentration of at least the first permeable solute and/or other permeable solutes than the eighth RO permeate **156***h*. The concentration of the first permeable solute (e.g., ethanol) in the eighth RO permeate **156***g* may be lower than the concentration in seventh RO permeate **156***g* and/or the eighth RO concentrate **154***h*. In examples,

the eighth RO permeate **156***h* may include the lowest concentration of one or both of the first impermeable solute and at least the first permeable solute in the system **900**. For example, the eighth RO permeate can be free (excepting residual amounts of less than about 1 wt %) of one or more of the first impermeable solute and at least the first permeable solute. Accordingly, essentially all of the first RO permeate is removed from the third RO permeate **156***c* (derived from the diluted draw stream **126**) entering the second set of regeneration apparatuses.

(104) The eighth RO concentrate **154***h* can be directed back to the seventh RO element **150***g* for further RO operation(s). The eighth RO concentrate **154***h* can be combined with the fourth RO permeate **156***d* at a point F prior to the seventh RO element **150***g*. The eighth RO permeate **156***h* may be removed from the system **900** as it exits the eighth RO element **150***h*. For example, the eighth RO permeate **156***h* can be directed to a tank, pipe, wastewater repository, or further water treatment apparatuses, outside of the system **900**.

(105) Points A, B, C, D, E, F may include one or more of pipeline(s), valve(s), tank(s), mixing vessel(s) or apparatuses, pump(s), or other equipment configured to mix, control movement, and/or contain a liquid therein. While points A, B, C, D, E, F are described as positions in the system **900**, points A, B, C, D, E, F can indicate an operation of combining the streams converging thereat.

(106) Any of the RO elements in the system **900** can include any of the RO membranes disclosed herein, such as a standard RO membrane or a low rejection RO membrane. Accordingly, any of the RO elements in the system **900** can be operated at any of the pressures disclosed herein. The operations and regeneration apparatuses disclosed above can be carried out in different orders, such as recovering a first permeable solute prior to recovering a first impermeable solute. In some embodiments, a system can include at least a first set of draw regeneration apparatuses to recover a first permeable concentrate (or impermeable concentrate) and a second set of draw regeneration apparatuses to recover a second permeable concentrate (or impermeable concentrate). Draw recovery of one or more permeable concentrates or impermeable concentrates may be carried out in any order using the techniques and systems disclosed herein.

(107) In some examples, the system **900** can dewater the feed stream **112** having a volume of about 900 liters and an ethanol content of about 7% ABW. The feed stream can be dewatered in the FO element **110** using the draw stream **122** having a volume of about 685 liters, an ethanol concentration (e.g., first permeable solute) of about 27.4% ABW and a glycerol concentration (e.g., first impermeable solute) of about 10 wt %. The resulting concentrated feed stream **116** includes a volume of about 335 liters and an ethanol content of about 18.8% ABW. The resulting diluted draw stream **126** can include a volume of about 1250 liters, a glycerol concentration of about 5.5 wt %, and an ethanol concentration of about 15 wt %.

(108) The diluted draw stream **126** is combined with the third RO permeate **156***c* and second RO permeate **156***b* prior to the first RO element **150***a*. The combined flow into the first RO element **150***a* includes a volume of about 2145 liters having an ethanol concentration of about 17% ABW and glycerol concentration of about 5 wt %. The first RO element **150***a* outputs a first RO concentrate **154***a* having a volume of about 750 liters, an ethanol concentration of about 19% ABW and a glycerol content of about 12 wt %. The first RO element **150***a* outputs the first RO permeate **156***a* having a volume of about 1395 liters, ethanol content of about 16% ABW, and glycerol content of about 2 wt %. In some examples, the first RO element **150***a* can include an array of RO elements, such as at least 2 RO elements, about 2 to about 40, or about 2 to 5 RO elements.

(109) The first RO concentrate **154***a* is directed to the second RO element **150***b*, where the concentrate is further processed and the first RO permeate **156***a* is directed to the third RO element **150***c* for further processing. The second RO element **150***b* is configured as a low rejection RO element (e.g., operably at high pressures such as about 800 psi). The second RO element **150***b* outputs a second RO concentrate **154***b* having a volume of about 345 liters, an ethanol concentration of about 19% ABW, and a glycerol concentration of about 19 wt %. The second RO concentrate **154***b* is directed back to the FO element **110**. The second RO element **150***b* outputs the

second RO permeate **156***b* having a volume of about 405 liters, an ethanol concentration of about 19% ABW, and a glycerol content of about 5 wt %. The second RO permeate **156***b* is directed back to the first RO element **150***a* where it is combined with diluted draw stream **126** and third RO concentrate **154***c* for further RO processing.

(110) The first RO permeate **156***a* is received in the third RO element **150***c* and separated into the third RO concentrate **154***c* and third RO permeate **156***c*. The third RO concentrate **154***c* includes a volume of about 905 liters, ethanol concentration of about 19% ABW, and glycerol concentration of about 4 wt %. The third RO concentrate is combined with the diluted draw stream **126** and second RO permeate **156***b* at point A. The third RO permeate includes a volume of about 905 liters, an ethanol concentration of about 19% ABW and a glycerol concentration of about 3 wt % or less (e.g., less than about 1 wt %). At this point in processing, most of the glycerol is removed from the diluted draw stream **126** (as processed through RO elements **150***a*-**150***c*) which may be further processed via RO to recover (e.g., concentrate) the ethanol therein.

(111) The third RO permeate **156***c* is combined with the seventh RO concentrate **154***g* and the fifth RO permeate at point D prior to entering the fourth RO element **150***d* to form a combined solution. The combined solution includes a volume of about 3110 liters and ethanol concentration of about 14% ABW (with negligible amounts of glycerol therein). In the fourth RO element **150***d* the combined solution is separated into the fourth RO concentrate **154***d* and fourth RO permeate **156***d*. The fourth RO concentrate **154***d* has a volume of about 1385 liters and ethanol content of about 20% ABW. The fourth RO concentrate **154***d* is directed to the fifth RO element **150***e*, where it is combined with the sixth RO permeate **156***f* prior to reaching the fifth RO element **150***e*. The fourth RO permeate **156***d* has a volume of about 1725 liters and ethanol content of about 10% ABW. The fourth RO permeate **156***d* is directed to the seventh RO element **150***g* where it is combined with the eighth RO concentrate **154***h* prior to reaching the eighth RO element **150***h*.

(112) The volume of solution of the combination of the fourth RO concentrate **154***d* and the sixth RO permeate **156***f* is about 1720 liters and the ethanol content is about 19% ABW. In the fifth RO element **150***e*, the solution is separated into the fifth RO concentrate **154***e* having a volume of about 675 liters and ethanol concentration of about 32% ABW, and the fifth RO permeate **156***e* having a volume of about 1045 liters and ethanol concentration of about 15% ABW. The fifth RO concentrate **154***e* is directed to the sixth RO element **150***f* and the fifth RO permeate **156***e* is directed to the fourth RO element **150***d* for combination with additional streams as described above. In some examples, the fifth RO element **150***e* can include an array of RO elements, such as about 2 to 7 RO elements.

(113) The sixth RO element **150***f* receives the fifth RO concentrate **154***e* and separates it into the sixth RO concentrate **154***f* and the sixth RO permeate **156***f*. The sixth RO concentrate **154***f* has a volume of about 335 liters and ethanol concentration of about 37% ABW. At this point the ethanol concentration may be at its highest point in the system. The sixth RO permeate **156***f* includes a volume of about 335 liters and ethanol concentration of about 27% ABW. The sixth RO concentrate **154***f* is directed back to the FO element **110** where it is combined with the second RO concentrate **154***b* at point C prior to the FO element **110** to at least partially reform the draw stream **122**. The sixth RO permeate **156***f* is directed back to the fifth RO element **150***e* where it is combined with the fourth RO concentrate **154***d* prior to the fifth RO element **150***d*.

(114) Returning to the fourth RO permeate **156***d*, the combination of the eighth RO concentrate **154***h* and the fourth RO permeate **156***d* having a volume of about 2190 liters and ethanol concentration of about 8% ABW is separated in the seventh RO element **150***g*. The seventh RO element **150***g* outputs the seventh RO concentrate **154***g* and the seventh RO permeate **156***g*. The seventh RO concentrate **154***g* includes a volume of about 845 liters and an ethanol concentration of about 9% ABW. The seventh RO permeate **156***g* includes a volume of about 1035 liters and ethanol concentration of about 3% ABW. In some examples, the seventh RO element **150***g* can include an array of RO elements, such as about 2 to 7 RO elements (e.g., in series, each producing a

progressively more concentrated RO concentrate and progressively more diluted permeate; and/or in parallel, each producing a similarly concentrated RO concentrate and diluted permeate). The seventh RO concentrate **154***g* is directed to the fourth RO element **150***d* as disclosed above and the seventh RO permeate is directed to the eighth RO element **150***h*.

(115) The eighth RO element **150***h* separates the seventh RO permeate **156***g* into the eighth RO concentrate **154***h* and the eighth RO permeate **156***h*. The eighth RO concentrate includes a volume of about 465 liters and an ethanol concentration of about 6% ABW. The eighth RO concentrate **154***h* is directed back to the seventh RO element **150***g* for further processing. The eighth RO permeate includes a volume of about 560 liters and an ethanol concentration less than about 1% ABW (about 0.6% ABW). The eighth RO permeate **156***h* is substantially free of both glycerol and ethanol from the draw stream **122**. Accordingly, essentially all of the ethanol and glycerol are recycled to the draw stream **122**, thereby reducing material costs. The eighth RO permeate **156***h* can be removed from the system **900**.

(116) While ethanol and glycerol are used as the first permeable solute and first impermeable solute, respectively, in the above examples, it should be understood that any of the other permeable and/or impermeable solutes disclosed herein may be used alternatively or in addition to ethanol or glycerol, without limitation.

(117) The volumes and concentrations disclosed in the above examples are merely some examples, variations of larger and smaller volumes and/or concentrations are considered. Volumes and concentrations can vary depending on the species of the permeable and/or impermeable solutes, desired final concentration of the permeable and/or impermeable solutes, number of RO elements, etc. Volumes can be scaled, or adjusted as needed. For example, the volumes noted above can be increased or decreased by a factor of about 0.1 or more, such as about 0.1 to about 1000, about 1 to about 100, about 5 to about 50, about 10 to about 25, about 1 to about 10, about 3 to about 15, or less than about 20.

(118) The above examples may include one or more distillation apparatuses, more RO elements, less RO elements, one or more sets or combinations of any of the foregoing to remove or concentrate one or more permeable solutes from a diluted draw solution, or combinations of any of the foregoing. In some embodiments, the RO elements include an array of RO membranes that may be in arranged parallel or in series, or in any combination of parallel and series.

(119) In embodiments, at least some of the RO elements in the system **900** can be replaced by one or more distillation apparatuses. For example, the RO elements **150***d*-**150***h* can be replaced by at least one distillation apparatus (e.g., an array of distillation apparatuses plumbed in parallel and/or series) configured to separate one or more components of the diluted draw stream **126** or derivatives thereof such as third RO permeate **156***c*. In such embodiments, the at least one distillation apparatus can be operably coupled to the third RO element **150***c* and receive the third RO permeate therefrom. The distillation apparatus can separate the third RO permeate **156***c* into distillate(s) and permeate(s) (e.g., still bottoms or source liquid for the distillates). The distillate can include ethanol or any other permeable solute and the permeate can include water. The distillate (e.g., ethanol) can be operably coupled to the draw stream supply to at least partially regenerate the draw stream **122**. For example, ethanol distillate form the at least one distillation apparatus can be combined with the second RO concentrate **154***b* to at least partially regenerate draw stream **122**. The permeate can be directed to one or more downstream apparatuses such as a waste supply. Such embodiments can be used to concentrate an alcoholic solution, such as an alcoholic beverage, and regenerate the draw stream from the diluted draw stream back to a higher alcohol concentration than the feed stream.

(120) Block diagram of FIG. **9** is described as a system above and may also be considered as a block diagram of exemplary methods. Such methods can be accomplished in a continuous series of operations as described above or in a batch wise manner (e.g., each FO or RO element operation is carried out separately).

(121) Any of the systems disclosed herein can be configured as a countercurrent system or a co-current system. The systems disclosed herein can be used to dewater (e.g., concentrate) solutions containing one or more permeable and/or impermeable solutes, such as alcoholic beverages. Solutions can be concentrated via one or more techniques disclosed below.
(122) FIG. **10** is a flow diagram of a method **1000** for dewatering a solution. The method **1000** includes an act **1010** of introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system; an act **1020** of circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes than the feed solution; an act **1030** of generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution; and an act **1040** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a concentration of the at least one species of the one or more permeable solutes greater than or equal to a concentration of the at least one species in the feed solution.
(123) The act **1010** of introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include introducing a solution having at least alcohol therein into a forward osmosis system. The feed solution can include an alcohol containing solution or a beverage containing alcohol such as malt beverages, beer, wine, distilled liquor or spirits; a flavor extract; a dye extract, or a fermentation broth (e.g., for ethanol production). The feed solution can include one or more permeable solutes therein (methanol, ethanol, isopropanol, ethylene glycol, lithium, protons, pH, lactic acid, acetic acid, citric acid, boron and boron oxides, hydroxides, ammonia, etc.), and optionally, one or more impermeable solutes such as sugars (e.g., glucose, fructose, glycerol, etc.), VOCs, dissolved salts (e.g., an inorganic salt such as sodium chloride), proteins (e.g., flavor or color enhancing proteins). In some embodiments, one or more impermeable solutes can include one or more sugar alcohols or dissolved derivatives thereof, such as sorbitol, mannitol, maltitol, glycerol, erythritol, etc., or hydrogenated starch hydrolysates. The feed solution may have a first concentration of the one or more permeable solutes (and/or impermeable solutes) effective to create a first osmotic pressure therein.
(124) While in some embodiments, alcohol is described as a component of the feed solution separately, it should be understood that alcohol is a permeable solute of an alcohol containing solution (e.g., beverage) having less than 50% ABW, and for the purposes herein may be a permeable solute for solutions having greater than 50% ABW (e.g., include less than 50 wt % water). In some embodiments, prior to processing in the FO element(s), the feed solution can include an alcohol (e.g., ethanol) content of at least about 1% ABW, such as about 1% ABW to about 50% ABW, about 1% ABW to about 10 ABW, about 1% ABW to about 5 ABW, about 3% ABW to about 10 ABW, about 5% ABW to about 15 ABW, about 10% ABW to about 20 ABW, about 15% ABW to about 30 ABW, about 25% ABW to about 40 ABW, or less than about 50% ABW. In some embodiments, prior to processing in the FO element(s), the feed solution can include a permeable (and/or impermeable) solute(s) content or concentration (other than alcohol) of about 1 wt % (e.g., solute by weight) or more, such as about 1 wt % to about 50 wt %, about 5 wt % to about 40 wt %, about 10 wt % to about 35 wt %, about 15 wt % to about 30 wt %, about 5 wt % to about 20 wt %, less than about 30 wt %, less than about 40 wt %, about 1 wt % to about 20 wt %, about 20 wt % to about 40 wt %, or less than about 50 wt %. Individual solutes of multiple solute solutions (e.g., one or more permeable solutes and/or one or more impermeable solute containing solutions) can individually or collectively comprise any portion of the above noted wt % ranges.
(125) Introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include introducing an alcohol containing solution into any of the FO

systems or components thereof disclosed herein. For example, introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include using at least one FO element including at least one FO membrane having a polyamide support to separate the first side from the second side. Introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include using one or more of a pump, conduit, or valve. Introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include introducing the alcohol solution at a specific rate, such as about 1 gpm or more, or 1 gpm to about 30 gpm, about 3 gpm to about 20 gpm, about 5 gpm to about 15 gpm, or less than about 50 gpm. Introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include introducing the alcohol solution therein at a specific pressure, such as about 1 psi or higher, about 1 psi to about 100 psi, about 5 psi to about 50 psi, about 10 psi to about 20 psi, about 5 psi to about 10 psi, about 1 psi to about 50 psi, about 1 psi to about 5 psi, about 1 psi to about 10 psi, about 1 psi to about 15 psi, about 10 psi to about 20 psi, about 15 psi to about 50 psi, less than about 50 psi, or less than about 10 psi. The pressure can be supplied or regulated by one or more pumps.

(126) Introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system can include circulating the feed solution through an FO element one time, more than one time, or through more than one FO element (e.g., a plurality of FO elements in parallel and/or series).

(127) The act **1020** of circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes than the feed solution can include circulating a draw solution configured to allow/cause selective removal of one or more components of the feed solution. For example, the draw solution can include at least one permeable solute therein (e.g., methanol, ethanol, isopropanol, ethylene glycol, lithium, protons, pH, lactic acid, acetic acid, citric acid, boron and boron oxides, hydroxides, ammonia, etc.) in an amount such that the concentration differential between the first side and second side of the FO membrane on the permeable solute in the feed solution at least partially prevents the at least one permeable solute from crossing the FO membrane. If the concentration of the permeable solute in the feed solution is the same as the concentration of the same solute (and/or combination of solutes including one or more permeable solutes and/or one or more impermeable solutes) in the draw solution, and there is no water transfer from the feed stream to the draw stream (e.g., water flux less than about 0.1 LMH), the permeation of the permeable solute will be reduced. If the concentration of the permeable solute (and/or combination of solutes including one or more permeable solutes and/or one or more impermeable solutes) in the draw stream is less than the concentration in the feed stream, the permeable solute will transfer from the feed stream to the draw stream. If the concentration of the permeable solute in the feed solution is less than the concentration in the draw solution, the permeable solute will transfer from the draw stream to the feed stream. In some embodiments, a draw solution having a higher permeable solute content (and/or impermeable solute content, or combination thereof) of at least one species of the one or more permeable solutes (and/or impermeable solutes, or combination thereof) than the feed solution can be circulated through the second side. The concentration of permeable solute(s) (and/or combination of solutes including one or more permeable solutes and/or one or more impermeable solutes) in the draw stream can be used to control the permeation rate and therefore the concentration of the permeable solute in the feed stream concentrate. In some examples, water transfer from the feed stream to the draw stream (about 1 LMH or greater) will reduce the permeable solute concentration at the membrane surface, so an excess of permeable solute (and/or impermeable solutes) may be used (at least about 5% ABW more permeable solute in the draw stream for example). In some examples, the permeable solute(s) may hydrogen bond with water and the permeation may be related to water transfer, so an additional excess of permeable solute(s)

(and/or impermeable solutes) may be used (at least about 10% for example). The amount of excess permeable solute(s) in the draw stream/solution may be experimentally determined by dewatering a feed stream/solution and measuring the concentration of the permeable solute in the feed stream concentrate as a function of concentration in the draw stream. The rate of transfer of the permeable solute may be dependent on one or more of the chemical species of the permeable solute(s), temperature, water flux, membrane materials and properties, turbulence and mixing at the membrane surface, pressure, flow rates, and the concentration of other species (counter ions and co-solvents). For example, increasing the draw stream flow rate with respect to the permeate stream flow rate while maintaining the draw stream permeable solute concentration will decrease the dilution of the draw stream and increase the net transfer of permeable solute from the feed stream to the draw stream.

(128) In some embodiments, the draw solution can include at least the same concentration of or an excess of one or more permeable solutes (e.g., ethanol) in the feed solution. For example, the draw solution (either prior to or after cycling through the FO element) can include an alcohol content at least equal to the alcohol content of the feed solution, such as at least 1% ABW more than the feed solution, at least about 5% ABW more, at least about 10% ABW more, at least about 15% ABW more, about 1% ABW more to about 45% ABW more, about 5% ABW more to about 35% ABW more, about 10% ABW more to about 20% ABW more, about 1% ABW more to about 20% ABW more, about 5% ABW more to about 25% ABW more, or less than about 40% ABW more than the feed solution. It is to be understood, that % ABW is commensurate with wt % and can be used interchangeably. In some embodiments, circulating the draw solution can include using a draw solution having a permeable solute(s) content therein configured to maintain the permeable solute(s) content in the feed solution (stream). In some embodiments, circulating the draw solution can include using a draw solution having a content of one or more permeable solutes (e.g., species and amount) and/or impermeable solutes other than alcohol configured to maintain the content (e.g., species and amount) of the one or more permeable solutes in the feed solution. For example, the draw solution can include about 10 wt % more ethylene glycol than the feed solution, and during FO the ethylene glycol in the feed solution is retained therein due at least in part to the osmotic pressure (from the chemical potential) induced by the excess of ethylene glycol in the draw stream. In some embodiments, the draw stream has a lower amount of the one or more permeable solutes and/or impermeable solutes to induce the one or more permeable solutes in the feed solution to cross the FO membrane into the draw solution.

(129) In some embodiments, in addition to alcohol, at least one more permeable or impermeable solute may be added to or present in the draw solution (e.g., draw stream) to generate additional osmotic pressure and driving force to dewater the feed solution (e.g., feed stream) to a desired concentration. The impermeable solute(s) may be implemented using at least one compound that may be a food safe additive that is soluble in water, capable of generating adequate osmotic pressure with a selected flux (e.g., at least about 1 liters/m.sup.2/h (LMH)), well-rejected (non-permeable or substantially impermeable) by FO, RO or NF membranes to reduce draw loss into the feed and NF or RO permeate, or combinations thereof. The at least one more impermeable solute may include one or more inorganic salts, for example sodium chloride, magnesium chloride, or magnesium sulfate. The at least one more impermeable solute may include one or more sugar alcohols, for example sorbitol, mannitol, maltitol, glycerol, erythritol, etc. In some embodiments, the at least one more impermeable solute may include one or more hydrogenated starch hydrolysates. In some embodiments, the at least one more impermeable solute may include one or more proteins. In some embodiments, the at least one more impermeable solute may include one or more VOCs. Identical ranges of excess amounts of impermeable solutes as those disclosed herein for alcohol contents in the draw solution can be used for dissolved sugars, salts, or any other solutes in the draw solution in any combination and/or ranges thereof.

(130) Circulating a draw solution having one or more permeable solutes therein through a second

side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes in the feed solution can include circulating the draw solution through any of the FO systems or components thereof disclosed herein. Circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes in the feed solution can include circulating the draw solution in either a countercurrent configuration or a co-current configuration to the feed solution. Circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes than the feed solution can include circulating the draw solution into the FO element using one or more of a pump, a conduit, a valve, etc. Circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes than the feed solution can include circulating the draw solution at a specific pressure, such as at least about 1 psi, about 1 psi to about 100 psi, about 10 psi to about 50 psi, about 15 psi to about 100 psi, about 10 psi to about 25 psi, about 25 psi to about 50 psi, about 75 psi to about 100 psi, less than about 100 psi, about 1 psi to about 10 psi, about 1 psi to about 15 psi, about 10 psi to about 20 psi, about 15 psi to about 50 psi, less than about 50 psi, or less than about 10 psi. Circulating a draw solution having one or more permeable solutes therein through a second side of the forward osmosis system, the draw solution having a permeable solute concentration greater than or equal to at least one species of the one or more permeable solutes in the feed solution can include circulating a regenerated, reconstituted, or recirculated draw solution through the FO system.

(131) The act **1030** of generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution can include using an FO membrane in the FO element capable of allowing at least some water to cross from the first side to the second side of the FO element via the membrane. Generating a diluted draw solution in the second side of the forward osmosis system can include outputting the diluted draw solution to one or more downstream draw components, such as any of those disclosed herein (e.g., regeneration apparatus(es), pumps, tanks, conduits, valves, etc.). In some embodiments, generating a diluted draw solution includes removing at least some water from the alcohol solution while leaving at least some or all of the alcohol therein, via the FO membrane.

(132) The act **1040** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a concentration of the at least one species of the one or more permeable solutes greater than or equal to a concentration of the at least one species in the feed solution can include producing a product stream (e.g., concentrated feed stream) having a higher concentration of one or more permeable solutes (e.g., alcohol) and/or lower concentration of water therein than the feed stream. For example, producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a concentration of the at least one species of the one or more permeable solutes greater than or equal to a concentration of the at least one species in the feed solution can include producing a product stream having at least about 5% ABW more alcohol therein than the feed stream, such as about 5% ABW to about 50% ABW more, about 10% ABW to about 40% ABW more, about 15% ABW to about 35% ABW more, or about 20% ABW to about 30% ABW more alcohol therein than the feed stream. Producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a concentration of the at least one species of the one or more permeable solutes greater than or equal to a concentration of the at least one species in the feed solution can include outputting the concentrated feed solution (stream) to one or more downstream

product components, such as one or more conduits, pumps, valves, refrigerators, distribution apparatuses, storage mediums (e.g., storage tanks), point of sale packaging (e.g., packaged concentrated alcoholic beverages), or a delivery means, such as a truck, pipeline, tank, etc. In some embodiments, producing a product stream can include retaining at least some of the one or more permeable solutes (e.g., alcohol) and/or one or more impermeable solutes (e.g., sugars, etc.) in the feed stream.

(133) In some embodiments, the method **1000** can further include maintaining the permeable solute (e.g., alcohol, ethylene glycol, etc.) content and/or impermeable solute content of the draw solution. For example, the method **1000** can further include regenerating the draw solution from the diluted draw solution. Regenerating the draw solution from the diluted draw solution can include reconstituting (e.g., regenerating the draw solution) via one or more of at least one distillation apparatus or at least one RO element (e.g., low rejection RO and/or standard RO), or at least one addition of permeable solute(s) (e.g., alcohol) and/or impermeable solutes (e.g., glycerol or fructose) from at least a second source into the diluted draw solution. In some embodiments, the method **1000** can further include producing a permeate stream or distillate from the diluted draw solution. In some embodiments, producing the permeate stream or distillate from the diluted draw solution can include producing the permeate stream via reverse osmosis or distillation. In some embodiments, the permeate stream or distillate includes substantially pure water.

(134) In some embodiments, the feed stream permeable solute(s) content can be slightly higher than a target feed stream concentrate permeable solute(s) content (e.g., target % ABW), accounting for concentration, to avoid distillation or the addition of permeable solute(s) (e.g., ethanol) to the draw solution or diluted draw stream. In some examples, the permeable solute(s) (e.g., ethanol) lost in the permeate (not retained in the feed stream concentrate) may be distilled and used as fuel.

(135) In some embodiments, the feed solution may be introduced to the FO element (e.g., concentrated) at low temperatures (e.g., −5° C. to 15° C.) which may improve retention of VOCs and small molecules to preserve the nutrients and flavors of the feed stream concentrate. In some embodiments, the feed solution may be concentrated at ambient (e.g., 15° C. to 35° C.) or higher temperature (e.g., 35° C. to 80° C.) to improve rejection and reduce costs of cooling the feed solution or concentrate thereof. In some embodiments, a temperature gradient across the FO membrane (e.g., a colder first side, or hotter first side) may increase the efficiency of the FO membrane or reduce costs of cooling or heating the feed solution or concentrate thereof. In some embodiments, the feed solution may be concentrated at a temperature and draw composition where the ratio of water permeation to ethanol permeation is highest.

(136) The methods disclosed herein can be employed to provide concentrated alcoholic beverages suitable for reconstitution (e.g., rehydration) by addition of water at a selected time. In an example, an alcoholic solution having about 5% ABW is introduced into an FO element as an initial feed solution (e.g., feed stream). The desired final concentration of the dewatered alcoholic solution in this example is 30% ABW (e.g., 6X concentration). The primary outputs of some systems and/or methods disclosed herein could include the concentrated feed stream having about 30% ABW, and permeate stream including nearly pure water stream (approximately <1% ABW). The concentrated feed stream (concentrated feed solution) may then be sold as a 30% ABW concentrate for dilution by the consumer (or retail outlet, etc.) to produce a 5% ABW product upon reconstitution. In some examples, the system may be operated to produce a concentrated product (e.g., feed stream) of 15% ABW to produce a 2.5% ABW product after dilution by a consumer. In some examples, the system may be operated to produce a reject stream of 2.5% ABW to produce a 0.4% ABW product after dilution. In some examples, the system may be operated to produce a concentrated feed stream of any % ABW product. In some embodiments, the methods herein can be used to concentrate an alcoholic solution by 2× or more over the initial concentration of alcohol therein, such as about 2× to about 10×, about 3× to about 8×, about 4× to about 6×, about 2× to about 5×, more than about 5×, or less than about 10×.

(137) In some embodiments, the method **1000** can include reconstituting the concentrated feed solution, such as by adding an amount of water corresponding to the level of concentration of the concentrated feed solution. For example, a concentrated feed solution having a 5× concentration of alcohol and other solutes therein can be diluted by combining about 5× the weight of the concentrated feed solution in water, with the concentrated feed solution.
(138) FIG. **11** is a flow diagram of a method **1100** for dewatering an alcoholic solution using forward osmosis. The method **1100** includes an act **1110** of introducing an alcoholic beverage into a first side of a forward osmosis system; an act **1120** of circulating a draw solution in a second side of the forward osmosis system, the draw solution having an alcohol concentration greater than or equal to the alcoholic beverage; an act **1130** of generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution; an act **1140** of producing a product stream including a concentrated alcoholic beverage from the first side of the forward osmosis system; an act **1050** of regenerating the draw solution from the diluted draw solution; and an act **1050** of producing a permeate stream from the diluted draw solution.
(139) The act **1110** of introducing an alcoholic beverage into a first side of a forward osmosis system can include introducing one or more of beer, wine, distilled spirits (liquor), a malt beverage, any other alcoholic solution, or combinations thereof into the first side of an FO system. The act **1110** of introducing an alcoholic beverage into a first side of a FO system can be similar or identical to the act **1010** described above in one or more aspects. For example, the act **1110** can include introducing an alcoholic beverage into any of the FO systems disclosed herein. In some embodiments, introducing an alcoholic beverage into a first side of a forward osmosis system may include using a forward osmosis membrane having a polyamide support to separate the first side from the second side.
(140) The act **1120** circulating a draw solution in a second side of the forward osmosis system, the draw solution having an alcohol content greater than or equal to the alcoholic beverage can include circulating a draw solution configured to allow/cause selective removal of one or more components of the feed solution. The act **1120** circulating a draw solution in a second side of the forward osmosis system, the draw solution having an alcohol content greater than or equal to the alcoholic beverage can be similar or identical to the act **1020** described above in one or more aspects. For example, circulating a draw solution in a second side of the forward osmosis system, the draw solution having an alcohol content greater than or equal to the alcoholic beverage can include circulating a draw solution having an excess of one or more solutes in the feed solution including an alcohol content that is at least 1% ABW more than the feed solution, at least about 5% ABW more, at least about 10% ABW more, at least about 15% ABW more, about 1% ABW more to about 45% ABW more, about 5% ABW more to about 35% ABW more, about 10% ABW more to about 20% ABW more, about 1% ABW more to about 20% ABW more, about 5% ABW more to about 25% ABW more, or less than about 40% ABW more than the feed solution.
(141) The act **1130** of generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution can including using an FO membrane in the FO element capable of allowing at least some water to cross from the first side to the second side of the FO element via the membrane. Generating a diluted draw solution in the second side of the forward osmosis system can include outputting the diluted draw solution to one or more downstream draw components, such as any of those disclosed herein (e.g., regeneration apparatus(es), pumps, tanks, conduits, valves, etc.). In some embodiments, generating a diluted draw solution includes removing at least some water from the alcoholic beverage while leaving at least some of the alcohol therein, via the FO membrane.
(142) The act **1140** of producing a product stream including a concentrated alcoholic beverage from the first side of the forward osmosis system can include producing a product stream (e.g., concentrated feed stream) having a higher concentration of alcohol and/or lower concentration of

water therein than the feed stream **112**. For example, producing a product stream including a concentrated alcoholic beverage can include producing a product stream having at least about 5% ABW more alcohol therein than the feed stream, such as about 5% ABW to about 50% ABW more, about 10% ABW to about 40% ABW more, about 15% ABW to about 35% ABW more, or about 20% ABW to about 30% ABW more alcohol therein than the feed stream. Producing a product stream including a concentrated alcoholic beverage can include outputting the concentrated alcohol stream to one or more downstream product components, such as one or more conduits, pumps, valves, refrigerators, distribution apparatuses, storage mediums (e.g., storage tanks), point of sale packaging (e.g., packaged concentrated alcoholic beverages), or a delivery means, such as a truck, pipeline, tank, etc. The acts **1130** and **1140** can be carried out contemporaneously or simultaneously.

(143) The act **1150** of regenerating the draw solution from the diluted draw solution can include directing the diluted draw solution through one or more regeneration apparatus, such as any of those disclosed herein. For example, regenerating the draw solution from the diluted draw solution can include directing the diluted draw solution through at least one RO element and/or at least one distillation apparatus. Regenerating the draw solution from the diluted draw solution can include reconstituting (e.g., regenerating) the draw solution via one or more of at least one distillation apparatus or at least one RO element (e.g., low rejection RO and/or standard RO), or at least one addition of alcohol from at least a second source into the diluted draw solution. In some embodiments, regenerating the draw solution includes distilling the diluted draw solution. In some embodiments, regenerating the draw solution includes performing reverse osmosis and distillation on the diluted draw solution. In some embodiments, regenerating the draw solution includes performing one or more of low-rejection reverse osmosis, reverse osmosis, or distillation on the diluted draw stream or a derivative thereof. In some embodiments, regenerating the draw solution includes cycling the diluted draw solution through a first reverse osmosis process followed by a second reverse osmosis process.

(144) The act **1160** of producing a permeate stream from the diluted draw solution can include producing the permeate stream via reverse osmosis or distillation. In some embodiments, the permeate stream or distillate includes substantially pure water (e.g., <1% ABW). In some embodiments, producing a permeate stream from the diluted draw solution includes producing a substantially pure water permeate stream

(145) The method **1100** can further include recirculating the regenerated draw solution through the second side of the FO system. The method **1100** can include any acts and/or aspects thereof disclosed herein, such as with respect to method **1000**.

(146) In an embodiment, a method of dewatering a solution can include an act of introducing a feed solution having one or more permeable solutes into a first side of a forward osmosis system. The method of dewatering a solution can include an act circulating a draw solution having one or more permeable solutes and one or more impermeable solutes therein through a second side of the forward osmosis system. The method of dewatering a solution can include an act generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration than the draw solution. The method of dewatering a solution can include an act of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a desired concentration of the at least one species of the one or more permeable solutes; wherein a combined osmotic pressure of the one or more permeable solutes and the one or more impermeable solutes in the draw solution is greater than an osmotic pressure of the concentrated feed solution.

(147) The one or more permeable solutes can includes any permeable solutes disclosed herein, such as ethanol, and the one or more impermeable solutes can include any of the impermeable solutes disclosed herein, such as glycerol. The feed solution may include any feed solution disclosed herein, such as beer, non-alcoholic beer, wine, malt beverage, distilled spirits, or combinations

thereof. The at least one permeable solute in the feed stream can include any permeable solute(s) disclosed herein, such as an alcohol.
(148) In some embodiments, the draw solution may have a combined concentration of the one or more permeable solutes and one or more impermeable solutes equal to or greater than a concentration of one or more permeable solutes in the feed solution, such as at least about 1 wt % greater, at least about 5 wt % greater, or at least 10 wt % greater than a concentration of one or more permeable solutes in the feed solution. In some embodiments, the draw solution may have a combined concentration of the one or more permeable solutes and one or more impermeable solutes equal to or greater than a concentration of one or more permeable solutes in the concentrated feed solution, such as at least about 1 wt % greater, at least about 5 wt % greater, or at least 10 wt % greater than a concentration of one or more permeable solutes in the concentrated feed solution. The combined concentration of the one or more permeable solutes and the one or more impermeable solutes in the draw solution can induce a combined osmotic pressure that is greater than an osmotic pressure of the concentrated feed solution or feed solution.
(149) In some embodiments, the method may further include regenerating the draw solution from the diluted draw solution, such as by any technique or combination of techniques disclosed herein. For example, regenerating the draw solution from the diluted draw solution may include separating at least some of the one or more permeable solutes (e.g., ethanol) in the diluted draw stream from at least some of the impermeable solutes (e.g., glycerol) in the diluted draw stream. In some embodiments, regenerating the draw solution from the diluted draw solution may further include concentrating the at least some of the one or more permeable solutes (e.g., ethanol) or at least some of the impermeable solutes (e.g., glycerol), such as by RO operations and/or distillation(s).
(150) In some embodiments, a plurality of permeable solutes and/or water can be removed from the feed stream, such as to form a feed concentrate having a lower concentration of one or more of the plurality of permeable solutes and/or water than one or more of the draw stream, feed stream, and the diluted draw stream. For example, systems and methods disclosed herein can be used to remove water and alcohol from a feed stream to produce a reduced alcohol and/or non-alcoholic (e.g., less than about 0.5 wt % alcohol) feed concentrate. A reduced alcohol solution or beverage can include a non-alcoholic solution or beverage (e.g., having an alcohol concentration that is less than 0.5 wt %, less than 0.1 wt %). A reduced alcohol solution or beverage can include a non-alcoholic solution or beverage that is substantially free of alcohol, except a trace or residual amount.
(151) FIG. **12** is a block diagram of an FO system **1200** for concentrating a feed solution. The FO system **1200** includes at least one FO element **110** and at least one draw stream regeneration apparatus fluidly coupled to a draw stream source **124**. The draw stream regeneration apparatus can include at least one RO element **150** as shown, or can include at least one distillation apparatus, or can include at least one low rejection RO element and at least one RO element. During use, a feed stream **112** is fed into (e.g., circulated through) a first side **115** the FO element **110** from a feed stream source **114**. Simultaneously, a draw stream **122** is fed into (e.g., circulated through) a second side **125** of the FO element **110**. The FO system **1200** may be set up in co-current or countercurrent configuration. The FO element **110** can include an FO membrane **130** composed to allow one or more permeable solutes and/or water from the feed stream **112** to pass therethrough into the draw stream **122**, responsive to hydrostatic and/or osmotic pressure differential(s) on the FO membrane **130**. In embodiments, the systems and methods herein can include producing a product stream including a concentrated beverage having a higher alcohol content and reduced water content from the first side of the forward osmosis system.
(152) The draw solution in the draw stream **122** can include two or more solutes (e.g., permeable and/or impermeable solute(s)), such as ethanol and glycerol. The feed stream **112** can have a higher permeable solute(s) concentration (e.g., total solutes or specific species thereof, such as permeable solutes) than the draw stream **122**, while having a lower total solutes concentration (e.g., permeable and impermeable solutes) than the draw stream **122**. For example, the feed stream **112** can have a

higher permeable solute concentration (e.g., alcohol) than the draw stream **122**, while the draw stream has a higher total solutes concentration (e.g., glycerol and alcohol). The draw stream **122** can have a higher impermeable solutes concentration than the feed stream **112**. As the feed stream **112** passes through the FO element **110**, at least one permeable solute (e.g., ethanol) and water are removed via the FO membrane **130**, and passed into the draw stream **122**. The removal of water from the feed stream **112** forms the concentrated feed stream **116**, which may have a higher concentration of one or more species of solutes (e.g., impermeable solutes, such as glucose, etc.) than the feed stream **112**. Such higher concentrations may be due at least in part to the removal of water from the feed stream **112**. The removal of the at least one permeable solute from the feed stream **112** may cause the concentrated feed stream **116** to exhibit a lower concentration of the at least one permeable solute than the feed stream **112**. The removal of water and the at least one permeable solute from the feed stream **112** into the draw stream **122** via the FO membrane **130** may cause the diluted draw stream **126** to exhibit a higher water content and a higher concentration of the at least one permeable solute than the draw stream **122** and the concentrated feed stream **116**. The removal of water and the at least one permeable solute (e.g., ethanol) from the feed stream **112** into the draw stream **122** via the FO membrane **130** may cause the diluted draw stream **126** to exhibit a lower impermeable solute (e.g., glycerol) concentration than the draw stream **122**.

(153) The at least one permeable solute (e.g., ethanol) concentration of the draw stream **122** should remain less than the at least one permeable solute (e.g., ethanol) concentration of the feed stream **112** throughout the entirety of the FO element **110** and processes disclosed herein. For example, in a countercurrent operation, the draw stream **122** contacting the incoming feed stream **112** in the FO element **110** (e.g., draw stream that is at a tail end of the draw side of FO element/process) can have a higher concentration of the at least one permeable solute than the draw stream **122** entering the second side **125** (e.g., due to already absorbing some of the impermeable solute through the FO membrane **130**), but still have a lower concentration of the at least one permeable solute than the feed stream **112** entering the FO element **150** (adjacent thereto) at the tail end of the draw side or beginning of the feed side. Such a countercurrent configuration ensures that the at least one permeable solute is continually removed from the feed stream **112** (feeds solution) throughout the FO element **110** at a selected rate.

(154) The concentrated feed stream **116** can be directed to one or more downstream product components **118** (e.g., packaging or distribution apparatuses, reconstitution apparatuses, recirculation apparatuses, etc.). The concentrated feed stream **116** may include a concentrated beer or other alcoholic beverage that has had at least some of the alcohol removed therefrom, such as to make a non-alcoholic (e.g., less than 0.5 wt % alcohol) beverage concentrate. In embodiments, the concentrated feed stream **116** (e.g., non-alcoholic beverage concentrate) can be at least partially reconstituted (e.g., rehydrated) to form a non-alcoholic alcoholic beverage, such as at a point of sale. The non-alcoholic beverage may have an alcohol content of less than about 0.5 wt % alcohol, or less than 0.1 wt % alcohol after reconstitution.

(155) In embodiments, the diluted draw stream **126** can include a higher concentration of the at least one permeable solute (e.g., ethanol) and water content than the draw stream **122**. The draw stream **122** can be at least partially regenerated by at least one draw stream regeneration apparatus. The draw stream regeneration apparatus can include at least one distillation apparatus. The diluted draw stream **126** can enter the distillation apparatus and produce a retained stream (e.g., water) and an alcoholic stream (e.g., an alcohol-containing distillate). As shown, the draw stream regeneration apparatus can include the at least one RO element **150**. The RO element **150** can include a housing containing an RO membrane **136** separating a first side **151** from a second side **152**. The diluted draw stream **126** can be circulated through the RO element **150** through the first side **151** thereof. The diluted draw stream **126** can be pressurized to a selected pressure (e.g., via one or more pumps (not shown) to cause at least some of the water and/or solutes to pass therethrough. At least some of the water and/or permeable solutes can pass through the RO membrane **136** and into an RO

permeate **156** (e.g., alcoholic or alcohol containing stream) on the second side **152** of the RO element **150**. The diluted draw stream **126** passing through the first side **151** of the RO element **150** is concentrated into an RO concentrate **154**, which may include an at least partially regenerated draw stream. For example, the draw regeneration system can be configured to produce and RO concentrate **154** having a composition identical to or near to the draw stream **122**. The draw stream source **124** can include a pump configured to pressurize the draw stream **122** (e.g., RO concentrate **154** or a mixture containing at least some of the RO concentrate **154**) to a hydrostatic pressure suitable for use in the FO element **110**. In embodiments, the draw stream source **124** can include a fluid addition apparatus configured to add one or more components to the RO concentrate **154** effective to reconstitute the RO concentrate **154** to produce the composition of the draw stream **122**, such as adding one or more of water, glycerol, or even ethanol. Accordingly, the draw stream **122** can be at least partially regenerated and recirculated back to the FO element **110** for reuse in the FO system **1200**.

(156) In embodiments, the RO permeate **156** (e.g., alcoholic stream) can be removed from the FO system **1200**, or can be further processed to separate the at least one permeate (e.g., ethanol) from the water therein. The water and ethanol can be used for other, related processes, such as reconstitution of the draw stream **122**, or the concentrated feed stream **116**.

(157) In a specific example, an alcoholic beverage feed stream **112** with a flow rate of 12 GPM and an alcohol content of 5 wt % is delivered to the first (e.g., feed) side **115** of the FO element **110** or array of FO elements **110** (e.g., a having an FO membrane **130** or array of FO membranes **130**). The alcoholic beverage contains both alcohol and water, which are drawn from the feed stream **112** while the remainder of the components are retained, producing concentrated feed stream **116** with a flow rate of 2 GPM and an alcohol content of about 0.5 wt % to about 2.5 wt %, or less (e.g., at least about a 6× concentration factor). This concentrated feed stream **116** may later be rehydrated to the original volume with water, producing a reduced alcohol beverage with an alcohol content of about 0.1 wt % to about 0.5 wt %. This rehydration may occur immediately after removal of water and alcohol, or may happen at another location and/or time (e.g., after storage and/or transport).

(158) The draw stream **122** can have a flow rate of 40 GPM, an alcohol content of 0.25 wt %, and glycerol content of 10 wt %. The draw stream **122** is circulated through the second (e.g., draw) side **125** the FO element **110** or array of FO elements **110** (e.g., a having an FO membrane **130** or array of FO membranes **130**) in countercurrent with respect to the feed stream **112** (or co-current in some embodiments). As the ethanol and water are drawn through the FO membrane(s) **130** into the draw stream **122**, the draw stream **122** is diluted by both water and alcohol. The alcohol content of the draw stream **122** is less than the alcohol content of the feed stream **112** throughout the entirety of the process (e.g., the alcohol content of a portion of the draw stream **122** adjacent to (e.g., across the membrane from) a portion of the feed stream **112** is less than the alcohol content of the portion of the feed stream **112**, throughout all portions of the FO element(s) and related processes). The diluted draw stream **126** is produced with a flow rate of 50 GPM, alcohol content of about 1.38 wt % and glycerol content of about 8 wt %. This diluted draw stream **126** is fed to a draw recovery/regeneration apparatus which produces an at least partially regenerated draw stream as RO concentrate **154** and an alcoholic (waste) stream as RO permeate **156** with a flow rate of 10 GPM, alcohol content of about 5.9 wt % and glycerol content of less than about 0.1 wt %. The draw recovery process is further described with respect to FIGS. **15** and **16**).

(159) In embodiments, the systems disclosed herein, such as FO system **1200** can include a feed stream supply and a draw solution supply operably coupled to the system. For example, the system **1200** can include a supply of an alcohol solution fluidly coupled to the first side of the FO element **110** and a supply of a draw solution operably coupled to the second side of the FO element **110**. In embodiments, the draw solution can include an at least one permeable solute (e.g., alcohol) concentration less than the permeable solute (e.g., alcohol) concentration of the feed stream (e.g., alcohol solution) and a total solutes (e.g., alcohol plus glycerol) concentration higher than a total

solutes (e.g., ethanol and sugars) concentration of the feed stream (e.g., alcohol solution). For example, the draw solution can have a higher glycerol and ethanol concentration that the ethanol and sugars concentration of beer, while the ethanol concentration in the beer feed stream is higher than the ethanol concentration in the draw stream. Such draw and feed sources can provide a system that functions to concentrate (e.g., remove alcohol and/or water from) an alcoholic beverage. The systems disclosed herein can include at least one at least one draw solution regenerating apparatus operably coupled to the second side of the FO element and configured to receive output therefrom. The at least one draw solution regenerating apparatus can be similar or identical to any of those disclosed herein, such as including at least one of a reverse osmosis apparatus, a low-rejection reverse osmosis apparatus, a distillation apparatus, or one or more series of any combinations of the foregoing.
(160) FIG. **13** is a block diagram of an FO system **1300** for concentrating a feed solution. The (countercurrent) FO system **1300** includes the counter current FO system **1200** as described herein, and further includes at least another separation apparatus, such as to further separate components of the RO permeate (e.g., alcoholic stream) from a draw stream regeneration apparatus. The at least another separation apparatus can include at least one distillation apparatus **140** (in addition to the RO element of the system **1200** already present). The at least another at least another separation apparatus (e.g., at least one distillation apparatus **140**) can be used to recover/regenerate the draw stream **122** or one or more portions thereof, such as to separate alcohol from water in the RO permeate **156** (e.g., alcoholic stream).
(161) The an input of the distillation apparatus **140** can be operably coupled to the output of the second (e.g., water) side **152** of the RO element **150**. The distillation apparatus **140** receives the RO permeate **156** and outputs distillate stream **142** (e.g., alcoholic stream) and draw permeate **144** (e.g., still bottoms or retained stream). The distillation apparatus **140** outputs the draw permeate **144** to one or more downstream processes or apparatuses. The draw permeate **144** may include water (e.g., substantially pure water) and the distillate stream **142** may include alcohol.
(162) As the RO permeate **156** leaves the RO element **150**, the at least one distillation apparatus **140** can recover, recycle, or regenerate one or more components therein. For example, the at one least distillation apparatus **140** can separate ethanol from water in the RO permeate **156** to produce draw permeate **144** including water, and distillate stream **142** including alcohol. In embodiments, one or both of the draw permeate **144** (e.g., water) or draw distillate stream **142** (e.g., concentrated alcohol) can be used to regenerate the draw stream **122** (e.g., supplement a content of the at least partially regenerated draw solution), or reconstitute at least a portion of the feed stream **112** or concentrated feed stream **116**.
(163) The additional separation process at the at least one distillation apparatus **140** may be employed to further separate the waste stream (e.g., RO permeate **156**) of the first RO element **150**, producing a water stream (draw permeate **144**) and an alcoholic stream (distillate stream **142**) that may be recycled in various ways, including within the operation of the system. In an embodiment, RO permeate **156** is fed to the at least one distillation apparatus **140** to perform at least another separation process, thereby producing a water stream (draw permeate **144**) with a flow rate of about 9.65 gpm, an alcohol content of less than about 0.1 wt % and a glycerol content of less than about 0.1 wt %; and produce a concentrated alcohol stream (distillate stream **142**) with a flow rate of about 0.35 gpm, an alcohol content of 85 wt % and glycerol content <0.1 wt %. In some embodiments, the at least another separation apparatus may include or be an array of distillation columns. In some embodiments, the at least another separation apparatus may include or be an RO element or array of RO elements. The additional separation process associated with the use of at least another separation apparatus can be performed on-site or at a different facility than the initial concentration of the feed stream **112**.
(164) In embodiments, a raw feed stream entering the system can be augmented to control a concentration of one or more solutes therein, and/or to ensure that a selected amount of the one or

more solutes are removed therefrom in the FO element(s) **110**.

(165) To allow the process of concentrating a feed stream to more closely suit a particular application (e.g., obtain a lower concentration of ethanol in concentrated feed stream than in other applications), chemical components may be combined with the feed stream to increase the FO resonance time and/or decrease a water to ethanol removal ratio (e.g., allowing more ethanol to be removed than in identical processes with different feed stream compositions). In such a manner, the water to alcohol (e.g., ethanol) removal ratio can be controlled. For example, the ratio of water to alcohol removed from the system can be at least 1:0.1, such as about 1:0.1 to about 1:50, or about 1:0.5 to about 1:20, or about 1:1 to about 1:10. In embodiments, at least a portion of the concentrated feed stream **116** can be recirculated back into the system to augment a solute content of a raw feed stream entering the system.

(166) FIG. **14** is a block diagram of an FO system **1400** for concentrating a feed solution. The FO system **1400** includes the counter current FO system **1300** as described herein, and further includes at least one mixing apparatus **160**, at least one recirculation line **170**, at least a second RO element **150*b***, and at least one additional recirculation line **175**. The at least one mixing apparatus **160** may be located upstream from the FO element **110** and provide the feed stream **112** thereto. The at least one recirculation line **170** may be located downstream of an outlet of the first side **115** of the FO element **110** and receive at least a portion of the concentrated feed stream **116** therefrom. The at least one recirculation line **170** may circulate a portion of the concentrated feed stream **116** (e.g., concentrated feed solution) to the at least one mixing apparatus **160**. The at least one mixing apparatus **160** may combine a raw feed stream **111** with one or more of the portion of the concentrated feed stream **116** carried by the at least one recirculation line **170**, or an additional component **119** supplied from another source (e.g., at least a second RO element **150*b***).

(167) The system **1400** may include at least one draw solution regeneration apparatus. The at least one draw solution regeneration apparatus may include one or more of reverse osmosis modules, low-rejection reverse osmosis modules, or distillation apparatuses. For example and as described in more detail below, the system **1400** may include a first reverse osmosis element operably coupled to the second side of the forward osmosis element to receive a diluted draw stream therefrom and produce a first reverse osmosis permeate and a first osmosis reject; a distillation apparatus operably coupled to the first reverse osmosis element to receive the first reverse osmosis permeate therefrom and produce a distillate and draw permeate; and a second reverse osmosis element operably coupled to the distillation apparatus to receive the draw permeate therefrom and produce a second reverse osmosis permeate and a second reverse osmosis reject. In embodiments, the second draw concentrate may be operably coupled to the first draw permeate, such as via one or more conduits.

(168) The at least a second RO element **150*b*** may be located downstream from the at least one distillation apparatus **140** on the draw permeate **144** side thereof. The at least a second RO element **150*b*** may remove (e.g., polish) any remaining solutes (e.g., alcohol) from the draw permeate **144** (e.g., bottoms) exiting the distillation apparatus **140**. For example, the RO element **150** may remove most of the glycerin from the diluted draw stream **126**, the distillation apparatus **140** may remove most of the ethanol from the RO permeate **156**, and the at least a second RO element **150*b*** may remove any residual solutes (e.g., ethanol, VOCs, and/or glycerin) from the draw permeate **144**, to provide substantially pure water. The RO permeate **156*b*** (e.g., substantially pure water) may be removed from the system **1400** or directed back to the at least one mixing apparatus **160**, such as via the at least one additional recirculation line **175**. The RO concentrate **154*b*** (e.g., alcohol) may be recirculated back to the draw stream **122**, such as by combining the RO concentrate **154*b*** with the RO concentrate **154** prior to introducing the draw stream **122** into the FO element **110**. In examples, the RO permeate **156*b*** may form at least a portion of the at least one additional component **119**. The additional component **119** can include water or another component of the feed solution. For example, the at least one additional component **119** can include substantially pure water, such as one or more of tap water or water that is recirculated to the mixing

apparatus **160** from the at least a second RO element **150***b* via the at least one additional recirculation line **175**. In embodiments, additional components **119** may be added without the addition of a recirculated concentrate (e.g., such as via the recirculation line **170**), such as from an outside source, and may increase the FO resonance time, thereby increasing the total amount of alcohol removed from the feed stream.

(169) The at least one mixing apparatus **160** can include one or more valves, a manifold, a container, or other structure(s) configured to allow one or more fluids to mix. For example, the at least one mixing apparatus can include a junction (e.g., confluence of fluid streams) wherein the raw feed stream **111**, the at least one recirculation line **170**, and the additional component **119** are converged to form the feed stream **112**. Any of the raw feed stream **111**, the at least one recirculation line **170**, and the additional component **119** source can include one or more pumps configured to provide a selected flow rate and/or pressure of the raw feed stream **111** (e.g., beer), the concentrated feed stream **116** (e.g., concentrated beer), and the additional component **119** (e.g., recirculated pure water or tap water) effective to cause the feed stream **112** to have a selected concentration of the one or more solutes prior to entry into the FO element **110**. For example, an alcohol content lower than that in the raw feed stream **111** may be selected to achieve a selected alcohol content in the concentrated feed stream **116**, accordingly, the raw feed stream **111** can be supplemented with amounts of water and/or concentrated feed stream **116** (having a relatively minimal alcohol concentration of less than 0.5 wt %) can be mixed with the raw feed stream to provide the selected alcohol content in the resulting feed stream **112**. Accordingly, the concentration of one or more solutes in the feed stream **112** can be customized to provide a selected effect/product. Such examples may be used to “tune” the concentration of one or more solutes in the feed stream **112** to achieve a selected target concentration of one or more solutes in the concentrated feed stream **116**. The feed stream **112** can be tuned by adding water (e.g., tap water, softened water, distilled water, purified water, filtered water, ion exchanged water, deaerated water, municipal water, culinary water, boiled water, treated water, pH balanced water, water recycled from the distillation apparatus **140** and/or at least a second RO element **150***b*, or any other type of potable water) to the feed stream **112** at the additional component **119** such as via the mixing apparatus **160**. Such tuning may be achieved by active monitoring of the solute(s) concentration in the concentrated feed stream **116** and responsive thereto, automatically altering the concentration of one or more of the raw feed stream, the at least one additional component, and the concentrated feed stream **116**, such as with the mixing device. In examples, one or more sensors may be disposed in one or more circulation lines disposed between one or more elements of the system **1400**. In examples, tuning the concentration of the one or more solutes in the feed stream **112** may be used to provide a selected concentration factor of one or more solutes in one or both of the feed stream **112** or the draw stream **122**. For example, the concentration of the one or more solutes in the draw stream **122** may be at least 1.2 times (e.g., 1.5 times, 2 times, 2.5 times, or 3 times) the concentration of the one or more solutes in the feed stream **112** and may be higher than the concentration of the one or more solutes in the concentrated feed stream **116**. In examples, tuning the concentration of the one or more solutes in the feed stream **112** may be used to maintain the concentration or total amount of one or more solutes in the feed stream **112** through the FO element **110** to the concentrated feed stream **116**.

(170) The at least one recirculation line **170** may include one or more of a valve, a syphon, a pump, or any other device configured to remove a fluid from a fluid supply. The at least one recirculation line **170** may remove a portion of the concentrated feed stream **116** prior to delivery to one or more downstream product components **118**, such as at point G. For example a portion (e.g., about 1% to about 20%, 20% to about 40%, or about 40% to about 60%) of the concentrated feed stream **116** can be recirculated back through the FO element **110** to ensure that the resulting concentrated feed stream **116** has the selected concentration of the at least one permeable solute or a selected water content.

(171) In embodiments, the at least one recirculation line **170** can be used to recirculate substantially all of the concentrated feed stream **116** back through the at least one FO element **110**, such as to further remove any of the at least one permeable solute therein. In such embodiments, the concentrated feed stream **116** can be recirculated one or more times (e.g., 1-10 times) through the FO element **110** effective to produce a final product (e.g., concentrated feed stream **116**) having a selected concentration of the one or more permeable solutes (e.g., ethanol) or a selected water content. Accordingly, a discrete volume of the raw feed stream **111** or feed stream **112** may be run across the FO membrane of the FO element **110** multiple times to remove a selected amount of one or more solutes (e.g., alcohol) therein.

(172) In examples, one or more of a water stream (additional component **119**) or a portion of the concentrated feed stream **116** may be added, to the feed stream to achieve a concentrated feed stream **116** having a selected solutes content (e.g., 0.5 wt % or less of alcohol, and 0.1 wt % or less of glycerol). The additional component **119** can be substantially pure water (e.g., water having less than 0.1 wt % of alcohol and less than 0.1 wt % of glycerol) provided at a rate of about 5 gpm. The raw feed stream **111** can include about 5 wt % alcohol (e.g., ethanol) and can be provided at a rate of about 6 gpm. The concentrated feed stream **116** can be provided to the mixing apparatus **160** at a rate of about 1 gpm and have a concentration of about 0.5 wt % alcohol and 0.0 wt % glycerol. The combination the raw feed stream **111**, the concentrated feed stream **116**, and the water (e.g., additional component **119**) can result in feed stream **112** having about 2.5 wt % alcohol and about 0.0 wt % glycerol, which can be provided to the at least one FO element **110** at a rate of about 12 gpm. As the feed stream **112** is concentrated in the at least one FO element **110** against the draw stream **122**, the concentrated feed stream **116** is produced and the diluted draw stream **126** is produced. The draw stream initially includes about 0.25 wt % alcohol and about 10 wt % glycerol and a rate of about 40 gpm. As the draw stream **122** is circulated through the at least one FO element **110** (e.g., in a countercurrent flow against the feed stream **112**), the draw stream **122** picks up water and permeable solute(s), such as ethanol, from the feed stream **112** to produce diluted draw stream **126**. Diluted draw stream **126** may include an alcohol content of about 0.8 wt % alcohol, about 8 wt % glycerol, and may be provided at about 50 gpm.

(173) The concentrated feed stream **116** exits the FO element **110** and is sent to one or more downstream product components **118**, as disclosed herein. About 1 gpm of the concentrated feed stream **116** is recirculated back to the mixing apparatus **160** to reconstitute the feed stream **112**. The portion of the concentrated feed stream **116** for recirculation back to the feed stream **112** is removed at point G, prior to delivery of the concentrated feed stream **116** to the one or more downstream product components **118**.

(174) The diluted draw stream **126** is provided to the RO element **150** such as through a pump to provide a selected pressure and rate thereof, where the diluted draw stream **126** is separated into RO concentrate **154** and RO permeate **156**. RO concentrate **154** can include about 0.25 wt % alcohol, about 10 wt % glycerol, and be provided at a rate of about 40 gpm. RO concentrate **154** can be recycled through the second side of the FO system for reuse as draw stream **122**. The RO permeate **156** (e.g., waste stream of the RO element **150**) can include about 3 wt % alcohol, less than 0.1 wt % glycerol, and be provided at a rate of about 10 gpm. The RO permeate **156** can be processed through at least one distillation apparatus **140**.

(175) The RO permeate **156** can be separated into distillate stream **142** (e.g., alcoholic stream) and draw permeate **144** (e.g., water in a retained stream) in the at least one distillation apparatus **140**. The draw permeate **144** can be substantially pure water having less than 0.1 wt % alcohol and less than 0.1 wt % glycerol, and be provided at a rate of about 9.65 gpm. The distillate stream **142** (e.g., alcoholic waste) can include about 85 wt % alcohol (e.g., ethanol) and less than about 0.1 wt % glycerol, and be provided at a rate of about 0.35 gpm. The water of the draw permeate **144** can be used in other processes, such as to reconstitute to the concentrated feed stream **116** (e.g., make non-alcoholic beer having less than 0.1 wt % alcohol, alter the composition or concentration of the raw

feed stream **111** by addition thereto as an additional component **119**, or can be used in other processes or offsite. The distillate stream **142** can be further purified to a substantially pure permeable solute (e.g., pure ethanol), sold, recycled back into the draw stream **122**, or used in other processes (e.g., burned).
(176) The draw permeate **144** can be directed to at least a second RO element **150***b* to remove any residual solutes in the draw permeate **144**. For example, the draw permeate **144** may be 2% ABW or less (e.g., less than 1% ABW or less than 0.5 wt % ABW) after distillation, and the at least a second RO element **150***b* may remove substantially all of the alcohol therefrom. The at least a second RO element **150***b* may receive as input the draw permeate **144** (e.g., bottoms from the distillation apparatus **140**) and output RO concentrate **154***b* and RO permeate **156***b*. The RO concentrate **154***b* may be recirculated back to the RO permeate **156** stream prior to the distillation apparatus **140** or to the draw stream **122**, further purified to a substantially pure permeable solute (e.g., pure ethanol), sold, or used in other processes (e.g., burned). The RO permeate **156***b* (e.g., pure water) may be recycled back to the mixing apparatus via the at least one additional recirculation line **175**, such as for use in the at least one additional component **119**, disposed, disposed of, or may be recycled for used in water systems (e.g., culinary water, irrigation water, gray water, or municipal water).
(177) The FO systems disclosed herein can be run in countercurrent configuration to ensure that the one or more permeable solutes in the draw stream remain in a lower concentration than in the feed stream throughout the FO element **110**. One or more pumps can be positioned at any point in the system (e.g., between elements) to provide a selected pressure for the corresponding fluid stream.
(178) FIG. **15** is a block diagram of a draw recovery system **1500**. The draw recovery system **1500** includes a first plurality of draw recovery elements **150′** (e.g., modules) and a second plurality of draw recovery elements **150″**. The individual draw recovery elements of the first plurality of draw recovery elements **150′** and the second plurality of draw recovery elements **150″** may include any number of one or more of an RO element, a low-rejection RO element, a nanoporous membrane element, or a distillation apparatus, arranged in any order.
(179) In operation, the first plurality of draw recovery elements **150′** can produce an RO concentrate **154***c* and an RO permeate **156***d*. The RO permeate **156***d* can be directed to the second plurality of draw recovery elements **150″**. The RO concentrate **154***c* can be combined with another fluid (e.g., second RO permeate **156***ec* and/or water) and/or can be recirculated back to the FO systems disclosed herein as a combined RO concentrate **154′** (e.g., an at least partially regenerated draw solution) for further use. The second plurality of draw recovery elements **150″** can receive the permeate **156***d* and produce an RO concentrate **154***g* and a RO permeate **156***e*. The RO concentrate **154***g* can be directed to a downstream distribution apparatus (e.g., storage tanks, distribution lines etc.). The RO permeate **156***e* can be combined with another fluid (e.g., RO concentrate **154***c* and/or water) and/or can be recirculated back to the FO systems disclosed herein as combined RO concentrate **154′** (e.g., at least partially regenerated draw solution) for further use. For example, the RO concentrate **154***c* and the RO permeate **156***e* can be combined to form the at least partially regenerated draw solution (e.g., combined RO concentrate **154′**).
(180) In embodiments, the first plurality of draw recovery elements **150′** and the second plurality of draw recovery elements **150″** can be configured to separate and collect different components of the diluted draw stream **126** to at least partially regenerate the draw stream **122**. For example, the first plurality of draw recovery elements **150′** can be configured to remove at least some alcohol from the diluted draw stream **126** and collect glycerol (and some alcohol) in the RO concentrate **154***c*, while the second plurality of draw recovery elements **150″** can be configured to remove alcohol (e.g., ethanol) from the diluted draw stream **126** (e.g., from the first RO permeate made from the diluted draw stream **126**) as RO concentrate **154***g* and collect water (e.g., substantially pure water) as the RO permeate **156***e*. The glycerol (and small amount of alcohol) of the RO concentrate **154***c* can be combined with the water of the RO permeate **156***e* to form the combined RO concentrate

154′ to at least partially regenerate the draw stream **122**.

(181) In embodiments, the first plurality of draw recovery elements **150′** can include a first RO element **150***a*, a second RO element **150***b*, a third RO element **150***c*, and a fourth RO element **150***d*, each fluidly coupled to one another in series. For example, an RO concentrate **154***a* from the first RO element **150***a* (e.g., a high rejection RO element) can be fluidly coupled to an input of the second RO element **150***b* (e.g., a low rejection RO element) and the first RO permeate **156***a* can be fluidly coupled to the input of the fourth RO element **150***d* (e.g., a high rejection RO element). An RO concentrate **154***b* of the second RO element **150***b* can be operably coupled to the input of the third RO element **150***c* (e.g., a low rejection RO element) and the RO permeate **156***b* can be recycled back to and operably coupled to the input of the first RO element **150***a*.

(182) The RO permeate **156***c* of the third RO element **150***c* can be recycled back to the input of the second RO element **150***b*, such as mixing with the first RO concentrate **154***a* at point J prior to introduction into the second RO element **150***b* to form RO concentrate **154***a′*. The RO concentrate **154***c* can be output to the FO system (e.g., any FO system disclosed herein) for use as a draw stream or a portion thereof. For example, the RO concentrate **154***c* can be combined with an RO permeate **156***e* at point K to produce the combined RO concentrate **154′** (e.g., at least partially regenerated or recovered draw solution). The combined RO concentrate **154′** can have a solutes content (e.g., one or more permeable and one or more impermeable solutes content) similar or identical to the draw stream **122** (not shown).

(183) The fourth RO element **150***d* can output RO concentrate **154***d* to the input of the first RO element **150***a* and output RO permeate **156***d* to the fifth RO element **150***e* located in the second plurality of draw recovery elements **150″**. The RO concentrate **154***d* can be combined with the diluted draw stream **126** at point H, and with the second RO permeate **156***b* at point I, to form the diluted draw stream **126′** prior to introduction into the first RO element **150***a*. The fourth RO permeate **156***d* is directed to the second plurality of draw recovery elements **150″**.

(184) The plurality of draw recovery elements **150″** can include a fifth RO element **150***e*, a sixth RO element **150***f*, and a seventh RO element **150***g*. The fifth RO element **150***e*, sixth RO element **150***f*, and seventh RO element **150***g* can be operably coupled to one another and collectively be configured to output an RO concentrate **154***g* (e.g., an ethanol solution) and RO permeate **156***e* (e.g., substantially pure water). The fourth RO permeate **156***d* can be introduced into the fifth RO element **150***e*. The fifth RO element **150***e* (e.g., a high rejection RO element) can output a fifth RO concentrate **154***e* to the sixth RO element **150***f* and can output a fifth RO permeate **156***e* (e.g., substantially pure water) to one or more of an FO system for use in reconstituting the draw stream, to downstream components/processes such as reconstituting the concentrated feed stream (not shown), into the waste water system, or any other suitable use. For example, fifth RO permeate **156***e* can be mixed with the third RO concentrate **154***c* to form the combined RO concentrate **154′**, which may be used in or as a regenerated draw stream.

(185) The sixth RO element **150***f* (e.g., a high rejection RO element) can output sixth RO concentrate **154***f* to the input of the seventh RO element **150***g* and can output sixth RO permeate **156***f* to the input of the fifth RO element **150***e*. For example, the sixth RO permeate **156***f* can be mixed with the fourth RO permeate **156***d* at point L to form the RO permeate **156***d′*, prior to introducing the same into the fifth RO element **150***e*.

(186) The seventh RO element (e.g., high rejection RO element) can output a seventh RO concentrate **154***g* (e.g., a waste stream having a relatively high amount (5 wt % or more) of ethanol) and output a seventh RO permeate **156***g* (e.g., water and ethanol of a concentration lower than a seventh RO concentrate **154***g*). The seventh RO concentrate **154***g* can be output to one or more downstream components for further processing (e.g., separation of the ethanol therefrom in a distillation apparatus) or disposal. The seventh RO permeate **156***g* can be output to the input of the sixth RO element **150***f*. For example, the seventh RO permeate **156***g* can be mixed with the fifth RO concentrate **154***e* at point M to form RO concentrate **154***e′* prior to introduction of the same

into the sixth RO element **150***f*. Accordingly, the RO permeate from the first plurality of draw recovery elements **150′** (e.g., apparatuses) can be further processed to remove one or more solutes therefrom and/or to at least partially recover/regenerate the draw stream form the diluted draw stream **126**.

(187) While 4 and 3 elements are shown respectively for each plurality of draw recovery elements **150′** and **150″**, any number of elements can be used to provide a selected component content (e.g., concentration) in the respective permeates and concentrates.

(188) In embodiments, the system **1500** and a process of using the same can be used to concentrate an alcoholic beverage solution (while simultaneously removing at least some of the alcohol therefrom), such as to produce a reduced-alcoholic beer concentrate. The process can include receiving a diluted draw stream **126** having a concentration of about 1.38 wt % ethanol and about 8 wt % glycerol at a rate of about 50 gpm at the first plurality of draw recovery elements **150′**. The diluted draw stream **126** can be combined with fourth RO concentrate **154***d* at point H and with second RO permeate **156***b* at point I to form the diluted draw stream **126′** having about 1.54 wt % ethanol and about 7.6 wt % glycerol, and provided to the first RO element **150***a* at a rate of about 101.5 gpm. The first RO element can be a high rejection RO element and output the first RO concentrate **154***a* having an ethanol concentration of 1.6 wt % and a glycerol concentration of about 18.3 wt %, at a rate of about 35.5 gpm. The first RO element **150***a* can output the first RO permeate **156***a* to the fourth RO element **150***d*, the first RO permeate having an ethanol content of about 1.5 wt % and a glycerol content of about 1.8 wt %, at a rate of about 66 gpm.

(189) The first RO concentrate **154***a* can be mixed with third RO permeate **156***c* at point J to form the first RO concentrate **154***a′* having an ethanol concentration of 1.6 wt % and a glycerol content of about 17.8 wt %, at a rate of about 44 gpm. The first RO concentrate **154***a* can be introduced into the second RO element **150***b*, where the second RO element **150***b* outputs second RO concentrate **154***b* having an ethanol concentration of about 1.3 wt % and a glycerol concentration of about 34 wt %, at a rate of about 15.5 gpm. The second RO element **150***b* also outputs second RO permeate **156***b* having an ethanol concentration of about 1.7 wt % and a glycerol concentration of about 9.0 wt %, at a rate of about 28.8 gpm. As noted above, the second RO permeate **156***b* can be combined with the combined diluted draw stream **126** and fourth RO concentrate **154***d* at point I to form the diluted draw stream **126′**.

(190) The second RO concentrate **154***b* is circulated through the third RO element **150***c* which outputs the third RO concentrate **154***c* and the third RO permeate **156***c*. The third RO concentrate **154***c* includes about 1.1 wt % ethanol and about 55.6 wt % glycerol, and is provided at a rate of about 7.1 gpm. The third RO concentrate **154***c* can be output to at least partially regenerate the draw stream used in FO systems as disclosed herein. For example, the third RO concentrate **154***c* can be combined with the fifth RO permeate **156***e* (e.g., substantially pure water) at point K to form the combined RO concentrate **154′**, which may be used as a regenerated draw stream. The third RO permeate **156***c* can include about 1.5 wt % ethanol and about 15.5 wt % glycerol, and can be provided at a rate of about 8.2 gpm. The third RO permeate **156***c* can be combined with the first RO concentrate **154***a* at the point J to form the first RO concentrate **154***a′* as disclosed above.

(191) The fourth RO element **150***d* can output the fourth RO concentrate **154***d* and the fourth RO permeate **156***d*. The fourth RO concentrate **154***d* can include about 1.7 wt % ethanol and about 4.9 wt % glycerol, and be provided to the first RO element **150***a* via point H at a rate of about 23 gpm. As noted above the fourth RO concentrate **154***d* can be combined with the diluted draw stream **126** and the second RO permeate **156***b* to form the diluted draw stream **126′** at points H and I respectively. The fourth RO permeate **156***d* can include about 1.4 wt % ethanol and about 0.2 wt % glycerol, and be provided to the second plurality of draw recovery elements **150″** at a rate of about 43 gpm.

(192) The fourth RO permeate **156***d* can be mixed with a sixth RO permeate at point L to form the RO permeate **156***d′*. The RO permeate **156***d′* can include about 1.1 wt % ethanol and less than

about 0.1 wt % glycerol (e.g., a trace amount), and be provided to the fifth RO element **150***e* at a rate of about 81.5 gpm. The fifth RO element **150***e* of the second plurality of draw recovery elements **150**″ can receive the RO permeate **156***d*′. The fifth RO element **150***e* can output the fifth RO concentrate **154***e* having about 1.8 wt % alcohol and less than about 0.1 wt % glycerol, to the sixth RO element **150***f* at a rate of about 49 gpm. The fifth RO element **150***e* can output fifth RO permeate **156***e* having less than about 0.1 wt % alcohol and less than about 0.1 wt % glycerol (e.g., substantially pure water), to the one or more downstream processes, such as regenerating the draw stream at a rate of about 49 gpm. For example, the fifth RO permeate **156***e* can be combined with the third RO concentrate **154***c* to form the combined RO concentrate **154**′, which may be used as a regenerated draw stream in any of the FO systems disclosed herein.

(193) The fifth RO concentrate **154***e* can be combined with the seventh RO permeate **156***g* at point M to form the RO concentrate **154***e*′ prior to introduction of the same into the sixth RO element **150***e*. The RO concentrate **154***e*′ can have an ethanol content of about 1.8 wt % and a glycerol content of about 0.13 wt %, and can be provided to the sixth RO element **150***f* at a rate of about 64.5 gpm. The sixth RO element **150***f* can output sixth RO concentrate **154***f* having an ethanol content of about 3.4 wt % and a glycerol content of about 0.3 wt %. The sixth RO concentrate **154***f* can be provided to the seventh RO element **150***g* at a rate of about 26 gpm. The sixth RO element **150***e* can output sixth RO permeate **156***f* having about 0.8 wt % alcohol and less than about 0.1 wt % glycerol, to the fifth RO element **150***e* at a rate of about 49 gpm. The sixth RO permeate **156***f* can be combined with the fourth RO permeate **156***d* at the point L as disclosed above.

(194) The seventh RO element **150***g* can output seventh RO concentrate **154***g* having about 6 wt % ethanol and less than about 0.1 wt % glycerol, at a rate of about 10 gpm. The seventh RO concentrate **154***g* can be output to one or more downstream apparatuses, such as at least one distillation apparatus to separate the ethanol from the water therein. The seventh RO element **150***g* can output seventh RO permeate **156***g* having about 1.7 wt % ethanol and about 0.7 wt % glycerol, at a rate of about 15.5 gpm. The combined RO concentrate **154**′ can be used as a regenerated draw solution, as-is, or can be combined with further solutions (e.g., water, beer, glycerol, etc.) to form a regenerated draw solution for use with the FO systems and processes disclosed herein.

(195) FIG. **16** is a block diagram of a distillation apparatus **140**. The distillation apparatus **140** can be used with any of the systems and methods disclosed herein. The distillation apparatus **140** can include one or more stills. In embodiments, a plurality of distillation apparatuses **140** can be used with any of the systems or methods disclosed herein, such as to separate one or more components of a fluid stream (e.g., at least partially regenerate a draw solution from a diluted draw stream, separate components of an RO permeate, etc.). For example, the distillation apparatus can receive the diluted draw stream **126** and separate the diluted draw stream into distillate stream **142** and draw permeate **144**. The distillate stream **142** can include a higher concentration of one or more permeable solutes therein that the diluted draw stream **126**. For example, the distillate stream **142** can include a higher concentration of ethanol than the diluted draw stream **126**. The draw permeate **144** (e.g., still bottoms) can include a lower concentration of at least one solute (e.g., ethanol) than the diluted draw stream **126**. For example, the draw permeate **144** can have a lower concentration of ethanol therein, or can include water and one or more impermeable solutes (e.g., having less than about 0.1 wt % ethanol and about 10 wt % glycerol therein). In embodiments, the one or more of the draw permeate **144** or the distillate stream **142** can be further processed to separate one or more components thereof (e.g., purification). For example, the distillate stream **142** can be further processed to remove water from ethanol therein, such as to produce a substantially pure water and ethanol products for other uses. In embodiments, one or more of the draw permeate **144** or the distillate stream **142** can be processed in one or more distillation apparatuses, one or more RO elements, one or more FO elements, or combinations of any of the foregoing, to separate one or more components therein. Such processing of the diluted draw stream and derivatives thereof can ensure that the original solutions are utilized and recycled as much as possible.

(196) While some of the fluidic components and connections between elements disclosed herein are referred to as "streams," it is understood that the "streams" includes a solution and/or a fluidic coupling (e.g., conduits) between elements. For example, a feed stream comprises a feed solution, a feed solution may comprise a feed stream, and each can include a conduit extending between a feed source and an FO element.
(197) While FIGS. **12-16** are presented as systems, each of the flow diagrams of FIGS. **12-16** also depict processes of concentrating a solution and/or regenerating a draw solution used to concentrate the solution. Some embodiments, of the processes disclosed in FIGS. **12-16** are disclosed below, with respect to FIGS. **17** and **18**.
(198) FIG. **17** is a flow diagram of a method **1700** for concentrating a solution. The method **1700** can include the act **1710** of introducing a feed solution having at least one permeable solute into a first side of a forward osmosis system; the act **1720** of circulating a draw solution through a second side of the forward osmosis system in a countercurrent flow with respect to the feed solution, the draw solution having one or more solutes and a concentration of the at least one permeable solute that is lower than a concentration of the at least one permeable solute in the feed solution; the act **1730** of generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and higher at least one permeable solute concentration than the draw solution; the act **1740** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a lower water content and a concentration of the at least one permeable solute that is less than the concentration of the at least one permeable solute in the feed solution; the act **1750** of regenerating the draw solution from the diluted draw solution; and the act **1760** of recirculating the draw solution that has been regenerated through the second side of the forward osmosis system. In embodiments, one or more of the acts **1710-1760** can be performed in a different order than presented or may be omitted.
(199) In embodiments, the act **1710** of introducing a feed solution having at least one permeable solute into a first side of an FO system can include introducing a feed solution that includes ethanol into a first side of the FO system. Introducing a feed solution having at least one permeable solute into a first side of an FO system can include introducing a feed solution that includes at least about 1 wt % greater concentration of the at least one permeable solute than the concentrated feed solution. In embodiments, introducing a feed solution having at least one permeable solute into a first side of an FO system can include introducing one or more of beer, wine, a malt beverage, distilled spirits, or combinations thereof. In such embodiments, the at least one permeable solute can include an alcohol (e.g., ethanol). In embodiments, introducing a feed solution having at least one permeable solute into a first side of an FO system can include using at least one forward osmosis membrane having a polyamide support to separate the first side from the second side. In embodiments, the FO system can include a plurality of FO elements disposed in one or more of series or in parallel. In embodiments, introducing a feed solution having at least one permeable solute into a first side of an FO system can include introducing the feed solution at rate of at least about 1 gpm, or between about 1 gpm to about 200 gpm. In embodiments, the act **1710** of introducing a feed solution having at least one permeable solute into a first side of an FO system can include introducing a feed solution into any of the systems disclosed herein.
(200) In embodiments, the act **1720** of circulating a draw solution through a second side of the FO system in a countercurrent flow with respect to the feed solution, the draw solution having one or more solutes and a concentration of the at least one permeable solute that is lower than a concentration of the at least one permeable solute in the feed solution can include circulating a draw solution having about 0.5 wt % alcohol or less (e.g., about 0.25 wt % alcohol or less) through the second side of the FO system. In embodiments, the act **1720** of circulating a draw solution through a second side of the FO system includes circulating the draw stream in a countercurrent flow compared to the feed stream. In embodiments, the act **1720** of circulating a draw solution

through a second side of the FO system in a countercurrent flow with respect to the feed solution can include circulating a draw solution having at least about 8 wt % glycerol (e.g., at least about 10 wt % glycerol) through the second side of the FO system.

(201) In embodiments, the one or more solutes can include a mixture of permeable solutes and impermeable solutes in a (e.g., total) concentration selected to produce a concentrated feed solution having a selected permeable solute concentration. In embodiments, one of the one or more permeable solutes in the draw solution and the at least one permeable solute in the feed solution can be identical, such as both including ethanol. In embodiments, the one or more solutes in the draw solution can include alcohol (e.g., ethanol) and glycerol and circulating a draw solution through a second side of the FO system can include circulating a glycerin and ethanol draw solution through the FO membrane. The ethanol content of the draw solution can be less than about 0.5 wt %, and the glycerol content of the draw solution can be more than about 8 wt %, prior to introduction of the draw solution into the FO element. In embodiments, the draw solution may have an initial solute (e.g., alcohol) concentration that is at least 1 wt % less (e.g., at least 1 wt %, 2 wt %, 3 wt %, 4 wt %, 5 wt %, or 10 wt % less, or ranges between any of the foregoing) than the solute concentration of the feed solution. The solute may include a single solute such as ethanol or glycerol or the solute may include a total solutes content. For example, the draw solution entering the FO element may contain less than 0.25 wt % alcohol and the feed solution entering the FO element (e.g., on an opposite side thereof in counter current flow) may have an ethanol content of at least about 5 wt %.

(202) In embodiments, the at least one permeable solute concentration of the draw stream is composed to have a concentration of the at least one permeable solute that is lower than the concentration of the permeable solute in the feed stream at single region of the FO element. For example, the ethanol concentration of the draw stream entering the FO element can be lower than the ethanol concentration of the feed stream exiting the FO element even though the ethanol concentration of the feed stream has been depleted by the time the feed stream exits the FO element.

(203) In embodiments, the act **1730** of generating a diluted draw solution in the second side of the FO system, the diluted draw solution having a higher water concentration and higher at least one permeable solute concentration than the draw solution can include passing one or more permeable solutes and/or water through the FO membrane, such as via one or more of osmotic and/or hydrostatic force. For example, generating a diluted draw solution in the second side of the FO system (and/or producing a product stream) can include removing at least one of the one or more permeable solutes (e.g., ethanol) and/or water from the feed solution via an FO membrane. In embodiments, the at least one permeable solute can include an alcohol (e.g., ethanol) and generating a diluted draw solution (and/or producing a product stream) can include removing alcohol from the feed solution via the FO membrane. In embodiments, generating a diluted draw solution in the second side of the FO system can include generating a diluted draw solution having a higher ethanol concentration than the draw solution by a multiple of at least about 2, such as about 2 to about 20, or about 3 to about 10.

(204) In embodiments, generating a diluted draw solution in the second side of the FO system can include generating a diluted draw solution having a total solutes concentration that is higher than the feed stream total solutes concentration, while the at least one permeable solute concentration (e.g., ethanol) remains lower than the at least one permeable solute concentration in the feed stream.

(205) In embodiments, the act **1740** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system can include producing any of the feed concentrate streams disclosed herein. In embodiments, the act **1740** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a lower water content and a concentration of the at least one

permeable solute that is less than the concentration of the at least one permeable solute in the feed solution can include producing an non-alcoholic beverage concentrate (e.g., beer having alcohol and water removed therefrom). In embodiments, the act **1740** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system can include producing an alcoholic beverage concentrate having a lower ethanol content than the feed stream. In embodiments, the act **1740** of producing a product stream including a concentrated feed solution from the first side of the forward osmosis system can include producing a beverage concentrate having an ethanol content of about 1 wt % or less, such as about 0.5 wt % or less.

(206) In embodiments, the act **1750** of regenerating the draw solution from the diluted draw solution can include processing the diluted draw solution in a draw solution regeneration or recovery system, such as any of those disclosed herein. For example, regenerating the draw solution from the diluted draw solution can include performing one or more of low-rejection reverse osmosis, reverse osmosis, or distillation on the diluted draw solution. In embodiments, regenerating the draw solution from the diluted draw solution can include cycling the diluted draw solution through a first reverse osmosis process (e.g., high or low rejection RO) followed by at least a second reverse osmosis process (e.g., high or low rejection RO). In embodiments, regenerating the draw solution from the diluted draw solution can include cycling the diluted draw solution through a first series of reverse osmosis processes followed by at least a second series of reverse osmosis processes. In embodiments, regenerating the draw solution from the diluted draw solution can include performing at least one distillation process on the diluted draw stream or a derivative thereof (e.g., an RO concentrate or permeate). For example, regenerating the draw solution from the diluted draw solution can include cycling the diluted draw solution through at least one reverse osmosis process followed by at least one distillation process. In examples, the diluted draw solution may be polished to remove or recover substantially all non-water components therein. For example, the act **1750** may include cycling the draw solution (e.g., bottoms) through at least one additional reverse osmosis process after the at least one distillation process. In such examples, the diluted draw solution may be cycled through at least a first reverse osmosis process, the reverse osmosis permeate may be distilled, the bottoms from the distillation process (e.g., draw permeate) may be subjected to at least a second reverse osmosis process, and the reverse osmosis permeate (e.g., pure water) may be recycled for use in the feed solution (e.g., feed stream), sold, or used for other purposes. The one or more solutes removed in the first reverse osmosis process, the distillation process, and the second reverse osmosis process may be recycled to the draw solution to reconstitute the draw solution (e.g., draw stream). In embodiments, the second reverse osmosis concentrate may be recycled to the first reverse osmosis permeate stream prior to introducing the first reverse osmosis permeate into the distillation process. In embodiments, regenerating the draw solution from the diluted draw solution can include using any of the systems disclosed herein in any of the ways disclosed herein. In embodiments, regenerating the draw solution from the diluted draw solution can include forming a regenerated draw solution having a composition (e.g., chemical content and concentrations) similar or identical to the draw solution. In embodiments, regenerating the draw solution from the diluted draw solution can include adding one or more of water or at least one additional component to the at least partially regenerated draw solution to form the regenerated draw solution.

(207) In embodiments, the act **1760** of recirculating the draw solution that has been regenerated through the second side of the forward osmosis system can include circulating the regenerated/recovered draw solution through the second side of the FO element. In embodiments, recirculating the draw solution that has been regenerated through the second side of the forward osmosis system can include pressuring the regenerated draw solution to a pressure and rate of delivery suitable for use in the second side of the FO system, such as any of those pressures or rates disclosed herein.

(208) In embodiments, the method **1700** can further include producing a permeate stream from the

diluted draw solution. In examples, the diluted draw solution may be polished to remove substantially all non-water components therefrom. For example, the method **1700** may include cycling the draw solution through at least one additional reverse osmosis process after the at least one distillation process. In such examples, the diluted draw solution may be cycled through at least the first reverse osmosis process, the reverse osmosis permeate may be distilled in a distillation process, the bottoms (e.g., water) from the distillation process may be subjected to at least the second reverse osmosis process, and the second reverse osmosis permeate (e.g., pure water) may be recycled for use in the feed solution, sold, or used for other purposes. In embodiments, the permeate stream (second reverse osmosis permeate) can be substantially pure water (e.g., water having less than about 0.1 wt % alcohol and less than about 0.1 wt % glycerol).

(209) In embodiments, the method **1700** can further include at least partially reconstituting the concentrated feed solution. For example, at least partially reconstituting the concentrated feed solution can include adding water (e.g., from the second reverse osmosis permeate) to the concentrated feed solution (e.g., beer) to form a partially reconstituted feed solution (e.g., non-alcoholic beer). For example, at least partially reconstituting the concentrated feed solution can include adding water (e.g., tap water, softened water, distilled water, purified water, filtered water, ion exchanged water, deaerated water, municipal water, culinary water, boiled water, treated water, pH balanced water, water recycled from the distillation apparatus **140** and/or at least a second RO element **150***b*, or any other type of potable water) and at least one permeable solute to the concentrated feed solution (e.g., beer) to form an at least partially reconstituted feed solution (e.g., lower alcohol content beer, than the alcohol content of the feed solution). In embodiments, at least partially reconstituting the concentrated feed solution can include adding water to the concentrated feed solution from (e.g., that was recovered via one or more diluted draw solution recovery techniques, such as any of those disclosed herein). For example, water, such as a water RO permeate, can be combined with the feed solution or concentrated feed solution to at least partially reconstitute the feed solution or control the concentration of the one or more solutes (e.g., alcohol) in the feed solution. In examples, adding water to the feed solution may include adding any water disclosed herein to the feed solution such as recycling water obtained from the permeate stream of the diluted draw solution (e.g., an RO permeate, distillation bottoms or RO permeate produced therefrom) to the feed solution.

(210) In examples, the method **1700** may include maintaining the concentration or total amount of alcohol in the feed solution. For example, when the maintenance of one or more solutes (e.g., alcohol) in any of the systems disclosed herein (e.g., in the feed solution or concentrated feed solution) is desired, the one or more solutes can be substantially completely recovered from the diluted draw solutions and permeate streams and may be recycled back to the feed solution entering the forward osmosis process. In such examples, the method **1700** may include using at least one additional reverse osmosis process after a distillation process to recover any residual amounts of the one or more solutes remaining in the bottoms of the distillation process (e.g., non-distillate liquid).

(211) FIG. **18** is a flow diagram of a method **1800** for concentrating an alcoholic solution via forward osmosis. The method **1800** can include an act **1810** of introducing an alcoholic beverage into a first side of a forward osmosis system; an act **1820** of circulating a draw solution in a second side of the forward osmosis system in a countercurrent flow with respect to the alcoholic beverage, the draw solution having an alcohol concentration lower than the alcohol concentration in the alcoholic beverage; an act **1830** of generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and higher alcohol concentration than the draw solution; an act **1840** of producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content from the first side of the forward osmosis system; an act **1850** of regenerating the draw solution from the diluted draw solution; and an act **1860** of producing a permeate stream from the diluted draw solution. In

embodiments, one or more of the acts **1810-1860** can be performed in a different order than as presented above, or may be omitted.

(212) The act **1810** of introducing an alcoholic beverage into a first side of an FO system can be similar or identical to the act **1710** disclosed above, in one or more aspects. For example, introducing an alcoholic beverage into a first side of an FO system can including introducing one or more of beer, wine, a malt beverage, distilled spirits, or combinations thereof into the first side of the FO system. In embodiments, introducing an alcoholic beverage into a first side of a forward osmosis system can include using a FO membrane having a polyamide support to separate the first side from the second side.

(213) The act **1820** of circulating a draw solution in a second side of the FO system in a countercurrent flow with respect to the alcoholic beverage, the draw solution having an alcohol concentration lower than the alcohol concentration in the alcoholic beverage can be similar or identical to the act **1720** disclosed above, in one or more aspects. For example, circulating a draw solution in a second side of the FO system in a countercurrent flow with respect to the alcoholic beverage can include circulating a draw solution having an alcohol concentration that is at least 1 wt % less (e.g., at least 1 wt %, 2 wt %, 3 wt %, 4 wt %, 5 wt %, or 10 wt % less, or ranges between any of the foregoing) than the alcohol concentration of the feed solution. For example, the draw solution entering the FO membrane may be less than 0.25 wt % alcohol and the feed solution entering the FO element (e.g., on an opposite side thereof in counter current flow) may have an ethanol content of at least about 5 wt %. In embodiments, circulating a draw solution in a second side of the FO system can include circulating a draw solution having a total solutes content that is higher than a total solutes content of the feed solution (e.g., the glycerol concentration of the draw solution can be higher than the total solutes content of the alcoholic beverage). In embodiments, the draw solution includes two or more solutes, such as one or more impermeable solutes and one or more impermeable solutes (e.g., ethanol and glycerol, respectively). In some examples, the draw solution can be circulated in a concurrent configuration with the feed solution.

(214) The act **1830** of generating a diluted draw solution in the second side of the FO system, the diluted draw solution having a higher water concentration and higher alcohol concentration than the draw solution can be similar or identical to the act **1730** disclosed above in one or more aspects. For example, generating a diluted draw solution in the second side of the FO system can include can include removing ethanol from the feed solution via the FO membrane.

(215) The act **1840** of producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content from the first side of the forward osmosis system can be similar or identical to the act **1740** disclosed above, in one or more aspects. For example, producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content can include removing at least some water and at least some alcohol from the alcoholic beverage via the FO membrane. In embodiments, producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content can include producing a concentrated beverage having a lower water content and a lower concentration of alcohol than the concentration of alcohol in the alcoholic beverage. For example, producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content can include producing a non-alcoholic beverage concentrate (e.g., beer having alcohol and water removed therefrom). In embodiments, producing a product stream including a concentrated beverage having a reduced alcohol content and reduced water content can include producing an alcoholic beverage concentrate having a lower ethanol content than the feed stream.

(216) The act **1850** of regenerating the draw solution from the diluted draw solution can be similar or identical to the act **1750** disclosed above in one or more aspects. For example, regenerating the draw solution from the diluted draw solution can include performing one or more of low-rejection reverse osmosis, reverse osmosis, or distillation on the diluted draw solution. In embodiments,

regenerating the draw solution from the diluted draw solution can include cycling (e.g., circulating) the diluted draw solution through a first reverse osmosis process followed by at least a second reverse osmosis process. In embodiments, regenerating the draw solution from the diluted draw solution can include cycling the diluted draw solution through a first series of reverse osmosis processes followed by at least a second series of reverse osmosis processes. In embodiments, regenerating the draw solution from the diluted draw solution can include cycling the diluted draw solution through at least one distillation process, such as at least one reverse osmosis process followed by at least one distillation process.

(217) The act **1860** of producing a permeate stream from the diluted draw solution can include producing a permeate via one or more of RO (e.g., low rejection or high rejection RO), distillation, or nanofiltration). In embodiments, producing a permeate stream from the diluted draw solution can include producing a substantially pure water permeate stream. For example, producing a permeate stream from the diluted draw solution can include producing a permeate via at least one RO process, distilling the permeate via at least one distillation process, and producing a second permeate from the bottoms (e.g., non-distillate liquid) of the distillation process. The second permeate may include substantially pure water, which may be disposed of, recycled for use in the feed solution, or recycled for later reconstitution of the feed solution using the concentrated feed solution. The one or more solutes (e.g., alcohol and/or glycerin) removed from the diluted draw solution, the RO permeate, and the bottoms may be recycled to reconstitute one or more of the feed solution or the draw solution. Accordingly, one or more solutes may be maintained in the system at a selected amount or concentration. The method **1800** may include maintaining the concentration or total amount of alcohol in the feed solution. For example, when the maintenance of one or more solutes (e.g., alcohol) in any of the systems disclosed herein (e.g., in the feed solution or concentrated feed solution solution) is desired, the one or more solutes can be substantially completely recovered from the draw solutions and permeate streams and may be recycled back to the feed solution entering the forward osmosis process. In such examples, the method **1800** may include using at least one additional reverse osmosis process after a distillation process to recover any residual amounts of the one or more solutes remaining in the bottoms (e.g., non-distillate liquid) of the distillation problems. The recovered residual amounts of the one or more solutes from the at least one additional reverse osmosis process may be combined with the permeate stream prior to introducing the permeate stream into the distillation apparatus. Accordingly, the permeable solute may be substantially completely recovered from the diluted draw stream and may be recycled for use in a regenerated draw stream.

(218) In embodiments, the method **1800** can further include recirculating the draw solution that has been regenerated through the second side of the forward osmosis system. In embodiments, recirculating the draw solution that has been regenerated through the second side of the forward osmosis system can be similar or identical to the act **1760** disclosed above, in or more aspects. For example, recirculating the draw solution that has been regenerated through the second side of the forward osmosis system can include pressurizing the regenerated draw solution in a pump to provide the same to the second side of the FO system at a selected pressure and/or rate.

(219) In embodiments, the method **1800** can further include combining at least some of the substantially pure water permeate (e.g., a permeate stream from the draw stream recovery apparatus(es)) with the concentrated beverage. In such embodiments, an at least partially reconstituted beverage can be formed.

(220) In embodiments, the method **1800** can include combining at least some of the permeate from the draw stream recovery apparatuses (e.g., substantially pure water) with the alcoholic beverage prior to introducing the alcoholic beverage into the first side of the forward osmosis system. Such addition can be used to dilute, maintain, or otherwise control the alcohol content of the alcoholic beverage entering the FO elements to a desired concentration of one or more solutes therein, such as to produce a selected one or more solutes content in the resulting concentrated beverage.

(221) In embodiments, the method **1800** can further include combining at least some of the concentrated beverage (e.g., concentrated feed solution) with an incoming raw feed solution (e.g., prior to the FO element) to form the feed solution introduced into the FO element. The method **1800** can further include combining substantially pure water with the combined raw feed solution and concentrated beverage to form the feed solution. In such a manner the one or more solutes content introduced into the FO element can be controlled to produce a desired one or more solutes content in the concentrated beverage produced by the FO element. Accordingly, one or more of the concentrated feed solution and one or more components of the diluted draw solution can be recirculated through the FO system and related methods to produce a selected one or more permeable solutes content in the product solution.

(222) In examples, the systems and methods herein may be used to maintain a concentration or amount of one or more solutes (e.g., alcohol) in a solution (e.g., feed solution or stream of an alcoholic beverage) while removing water therefrom. For example, a method for maintaining an amount or concentration of one or more solutes in the solution while removing water therefrom may include utilizing a higher concentration of at least one permeable solute in the draw solution than the feed solution (or the concentrated feed solution). The method may include introducing a feed solution having at least one permeable solute into a first side of a forward osmosis system which may be similar or identical to the act **1110** or **1710** in one or more aspects. The method may include circulating a draw solution through a second side of the forward osmosis system, the draw solution having two or more solutes and a concentration of the at least one permeable solute that is greater than a concentration of the at least one permeable solute in the feed solution which may be similar or identical to the act **1120** or **1720** in one or more aspects. The method may include generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and lower at least one permeable solute concentration than the draw solution which may be similar or identical to the act **1130** or **1730** in one or more aspects. The method may include producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a lower water content and a concentration of the at least one permeable solute that is higher than the concentration of the at least one permeable solute in the feed solution which may be similar or identical to the act **1140** or **1740** in one or more aspects. The method may include regenerating the draw solution from the diluted draw solution which may be similar or identical to the act **1150** or **1750** in one or more aspects. The method may include recirculating the draw solution that has been regenerated through the second side of the forward osmosis system which may be similar or identical to the act **1760** in one or more aspects. In examples, the at least one permeable solute may include alcohol. For example, the feed solution may include an alcoholic beverage such as one or more of beer, wine, or distilled spirits.

(223) The method may include circulating the diluted draw stream through a reverse osmosis element to separate at least some of the solutes (e.g., permeable and/or impermeable solutes) from the diluted draw stream. The reverse osmosis element may produce a reverse osmosis concentrate (e.g., reject) and a reverse osmosis permeate. The reverse osmosis permeate may be further processed. For example, the reverse osmosis permeate may be distilled to separate distillate (e.g., alcohol) from the draw permeate (e.g., still bottoms). The distillate may be recycled to regenerate the draw stream or to the feed stream. The draw permeate remaining after distillation may be further processed to separate any residual or remaining solutes from the draw permeate (e.g., still bottoms), such as to produce substantially pure water. The draw permeate may be processed in at least a second reverse osmosis element to produce a second reverse osmosis concentrate (e.g., substantially pure alcohol or another solute) and a second reverse osmosis permeate (e.g., substantially pure water). The second reverse osmosis concentrate may be recirculated to the reverse osmosis permeate exiting the first reverse osmosis element prior to entering the distillation apparatus to recover the solute(s) (e.g., alcohol) therein. In embodiments, the solute(s) recovered

from one or more of the reverse osmosis element, the distillation apparatus, and the second reverse osmosis element may be recycled to regenerate the draw solution.
(224) The method may include selectively controlling a concentration of the at least one permeable solute in the feed solution prior to introducing the feed solution into the forward osmosis system. For example, the at least one permeable solute concentration of the feed solution may be controlled by adding one or more of water or concentrated feed solution to the feed solution prior to introducing the feed solution into the forward osmosis system, such as disclosed herein with respect to FIG. **14**. In examples, selectively controlling a concentration of the at least one permeable solute in the feed solution prior to introducing the feed solution into the forward osmosis system may include sensing or detecting the concentration of the at least one permeable solute (e.g., alcohol) in one or more of the feed solution, the concentrated feed solution, or the diluted draw solution and responsive thereto, selectively adding one or more of water or concentrated feed solution to the feed solution to control the at least one permeable solute in the feed solution or concentrated feed solution. In examples, the selective control (e.g., addition of water or concentrated feed solution) can be carried out continuously to maintain a selected alcohol concentration in the concentrated feed solution.
(225) In examples, adding water to the feed solution can include adding one or more of tap water, softened water, distilled water, purified water, filtered water, ion exchanged water, deaerated water, municipal water, culinary water, boiled water, treated water, pH balanced water, water recycled from the distillation apparatus and/or at least a second RO element, or any other type of potable water, to the feed solution. In examples, selectively controlling a concentration of the at least one permeable solute in the feed solution may include cycling the diluted draw solution through at least a first reverse osmosis system to provide a first reverse osmosis permeate having a lower concentration of the two or more solutes and at least one permeable solute than the diluted draw solution. In examples, selectively controlling a concentration of the at least one permeable solute in the feed solution may include distilling the first reverse osmosis permeate to produce bottoms having a lower concentration of the two or more solutes and at least one permeable solute than the reverse osmosis permeate. In examples, selectively controlling a concentration of the at least one permeable solute in the feed solution may include cycling the bottoms through at least a second reverse osmosis system to provide a second reverse osmosis permeate that is substantially pure water. In examples, selectively controlling a concentration of the at least one permeable solute in the feed solution may include adding water to the feed solution. In examples, adding water to the feed solution may include recycling the substantially pure water from the second reverse osmosis permeate to the feed solution. In examples, the feed solution may include beer, wine, or distilled spirits and the at least one permeable solute may include one or more of glycerin or alcohol.
(226) The above described methods and systems can be used to form concentrated beer, wine, malted beverages, liquor, or other alcoholic solutions. The above described methods and systems can be used to form dewatered and/or non-alcoholic beer, wine, malted beverages, liquor, or other concentrates from previously alcohol-containing beverages. The methods and systems can also include acts and components to reconstitute the concentrated beer, wine, malted beverages, liquor, other alcoholic solutions, or concentrates via controlled addition of at least water thereto.
(227) Other specific forms of examples described herein may be used without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. For example, any of the individual acts of the methods and components of the systems disclosed herein can be used with any of the other methods and systems disclosed herein. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

Claims

1. A method for removing one or more solutes and water from a solution, the method comprising: introducing a feed solution having at least one permeable solute into a first side of a forward osmosis system; circulating a draw solution through a second side of the forward osmosis system, the draw solution having one or more solutes and a concentration of the at least one permeable solute that is lower than a concentration of the at least one permeable solute in the feed solution; generating a diluted draw solution in the second side of the forward osmosis system, the diluted draw solution having a higher water concentration and higher at least one permeable solute concentration than the draw solution; producing a product stream including a concentrated feed solution from the first side of the forward osmosis system, the concentrated feed solution having a lower water content and a concentration of the at least one permeable solute that is lower than the concentration of the at least one permeable solute in the feed solution; regenerating the draw solution from the diluted draw solution.
2. The method of claim 1, wherein regenerating the draw solution from the diluted draw solution includes: processing the diluted draw solution in a first reverse osmosis element to produce a first reverse osmosis permeate and a first reverse osmosis concentrate; distilling the first reverse osmosis permeate in a distillation apparatus to produce a retained stream and a distillate; and processing the retained stream from the distillation apparatus with at least a second reverse osmosis element to produce a second reverse osmosis permeate and a second reverse osmosis concentrate; wherein the second reverse osmosis concentrate includes the at least one permeable solute and the second reverse osmosis permeate includes water.
3. The method of claim 2, further comprising recirculating the second reverse osmosis concentrate to the first reverse osmosis permeate exiting the first reverse osmosis element.
4. The method of claim 1, wherein the at least one permeable solute includes alcohol.
5. The method of claim 1, wherein the feed solution includes one or more of beer, wine, or distilled spirits.
6. The method of claim 1, further comprising adding water to the feed solution prior to introducing the feed solution into the first side of the forward osmosis system.
7. The method of claim 1, wherein circulating a draw solution through a second side of the forward osmosis system includes circulating the draw solution through the second side in a countercurrent flow with respect to the feed solution in the first side.
8. The method of claim 1, wherein regenerating the draw solution includes performing one or more of low-rejection reverse osmosis, reverse osmosis, or distillation on the diluted draw solution.
9. The method of claim 1, wherein regenerating the draw solution includes cycling the diluted draw solution through a first reverse osmosis process followed by at least a second reverse osmosis process.
10. The method of claim 1, wherein regenerating the draw solution from the diluted draw solution includes cycling the diluted draw solution through a first series of reverse osmosis processes followed by at least a second series of reverse osmosis processes.
11. The method of claim 1, further comprising combining at least some of the concentrated feed solution with the feed solution prior to introducing the feed solution into the first side of the forward osmosis system.
12. A system comprising: a forward osmosis element including at least one selectively permeable forward osmosis membrane separating a first side of the forward osmosis element from a second side of the forward osmosis element; a supply of an alcoholic beverage containing ethanol fluidly coupled to the first side of the forward osmosis element; a supply of draw solution fluidly coupled to the second side of the forward osmosis element, the draw solution having one or more solutes and a concentration of ethanol that is less than a concentration of ethanol in the feed solution; a

reverse osmosis element operably coupled to the second side of the forward osmosis element, the reverse osmosis element including a reverse osmosis membrane defining a first side of the reverse osmosis element and a second side of the reverse osmosis element, wherein the reverse osmosis element is configured to receive a diluted draw solution from the forward osmosis element in the first side of the reverse osmosis element and produce at least a portion of a regenerated draw solution; and a draw solution regenerating apparatus configured to regenerate draw solution from diluted draw solution through the second side of the forward osmosis element.
13. The system of claim 12, wherein the diluted draw solution has a higher water concentration and higher ethanol content than the draw solution.
14. The system of claim 12, wherein the forward osmosis element is configured to produce a product stream including a concentrated alcoholic beverage from the first side of the forward osmosis system, the concentrated alcoholic beverage having a lower water content and a concentration of ethanol that is lower than the concentration of ethanol in the alcoholic beverage.
15. The system of claim 12, wherein the reverse osmosis element is further configured to produce a first reverse osmosis permeate and a first reverse osmosis concentrate.
16. The system of claim 15, wherein the draw solution regenerating apparatus includes: a distillation apparatus operably coupled to the first reverse osmosis element to receive the first reverse osmosis permeate therefrom and produce a distillate and retained stream; and a second reverse osmosis element operably coupled to the distillation apparatus to receive the retained stream therefrom and produce a second reverse osmosis permeate and a second reverse osmosis concentrate.
17. The system of claim 16, wherein the draw solution regenerating apparatus is further configured to recirculate the second reverse osmosis concentrate to the first reverse osmosis permeate exiting first reverse osmosis element.
18. The system of claim 12, wherein a reject side of the draw solution regeneration apparatus is fluidly coupled to the supply of the draw solution and configured to supply the regenerated draw solution thereto.
19. The system of claim 12, wherein a permeate side of the draw solution regeneration apparatus is fluidly coupled to one or more of the supply of the feed solution or a product side of the forward osmosis element, and is configured to supply a water permeate thereto.
20. The system of claim 12, wherein the feed solution includes beer, wine, or distilled spirits.