Electromechanical Desalinator

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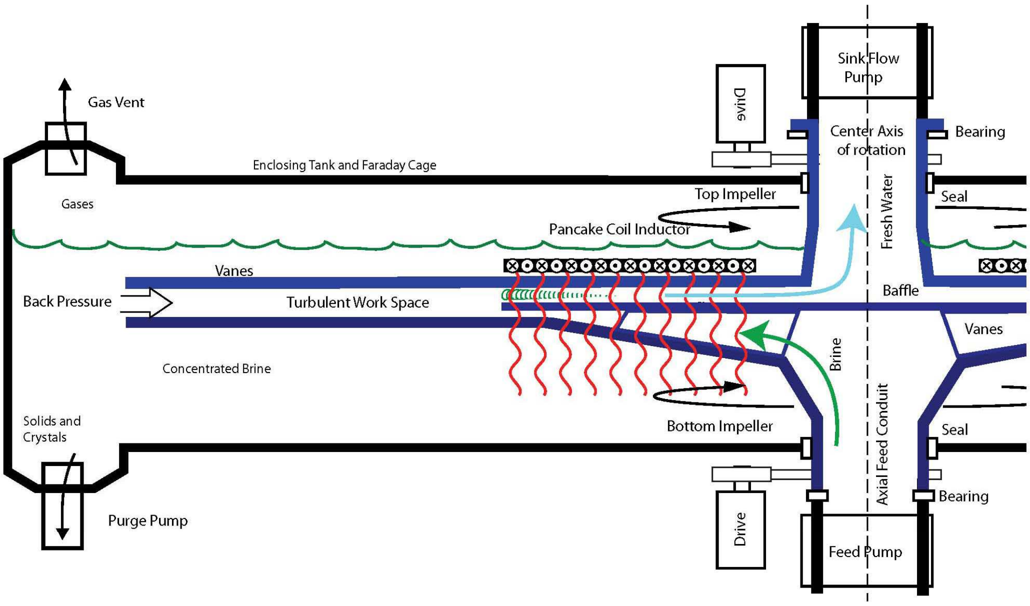
A Continuous Brine Separator

The Vorsana Electromechanical Desalinator is a simple electro-mechanical separator, a variation of the McCutchen Processor™, that can be used for more effective desalination and other brine processing in a continuous, one-pass process. No added heat, chemicals, dead-end filters, membranes, ion exchange, electrodialysis, or distillation are needed. Counter-rotating disks within the separator create powerful radial flow effects that use centrifugal force to separate the brine components of different weights, while a RF pancake coil electrical inductor controls the flow of components according to their electrical properties. These combined effects create a continuous radial counterflow pattern, with purified fluids flowing inward toward the central axis and increasingly concentrated waste products flowing outward into a collection tank. It represents an inexpensive and easily scalable improvement in industrial and municipal wastewater processing, cleaning of brine waste from oil and gas production, and field water purification.

Summary

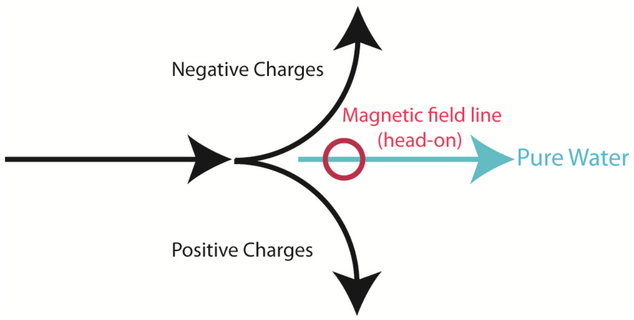
A fluid mixture is continuously separated between counter-rotating coaxial centrifugal disk impellers. An axial feed source flow of the fluid mixture flows outward from underneath a baffle between the disks, where the action of the oppositely rotating disk impellers creates a working zone of extreme turbulence organized into rapid vortices.



The source flow outward is amplified by curved impeller blades on the rotating baffle, and a sink flow inward for fresh water is created by a sink flow suction pump at the axis above the baffle. The radial outward feed flow goes outward into a surrounding annular tank, filling it and creating back pressure inward. This back pressure also helps creates the sink flow inward over the baffle. The baffle is a barrier between the source flow outward and the sink flow inward toward the axis. The sink flow passes between the rapidly rotating baffle disk and the upper disk surface, which is either static or counter-rotating relative to the baffle disk. The different motion of these two disk surfaces passing close to each other creates a working zone where the fluid components are separated by controlled vortex turbulence and electrical effects.

The purely mechanical separation mechanism exploits the density and conductivity difference between brine and fresh water. The von Karman swirling flow induced by the counter-rotating disks creates a radial tree pattern of rapidly swirling vortices, which remain stable and coherent because of the continuous suction of the sink flow. Within these small vortices, the extremely high centrifugal force separates the fluid by weight. The heavier components such as brine and salts, are flung outward, and lighter components, such as fresh water, move into the vortex cores and are continuously drawn out the ends of the vortices into the axial sink flow outlet.

At the same time, electrical separation is being done using an inductor. An RF pancake coil inductor, located above the working zone sink flow, induces a barrier of increased viscosity and repulsion in any salts and other ions attempting to enter the sink flow, according to the Lorentz force. Unlike the electrolytes in brine, pure water is unaffected by the magnetic field lines caused by the inductor, so the pure water slips through in the vortices to the axial sink flow outlet, while the brine electrolytes are deflected by the magnetic field lines and become viscous in the turbulent flow. Therefore, the salts jam up at this magnetic barrier and are pushed away into the boundary layer at the baffle, where they get centrifugally moved outward toward the annular tank. Thus, as the sink flow converges to the axial outlet, it is increasingly low in salinity.



This radial counterflow, of brine radially out and fresh water radially in, concentrates the salts, including calcium carbonate and gypsum, in the annular tank. Agitation and supersaturation provide favorable conditions for further crystallization of these salts in the tank, where they can be extracted by a solids valve in the bottom. Gases produced from the crystallization can be collected by a gas valve in the top of the tank.

No pre-treatment of the source flow feed, to remove particulates or scaling salts, is necessary. The energy requirement is small because the work is primarily the mechanical energy to run the rotating disks of the separator, the induction coil, and the inlet and outlet pumps. Thus raw seawater or polluted river water could be processed by a simple engine.

The Problem of Brine Processing

Brine can be broadly defined as a fluid mixture of water with salts and other components. Previous attempts at brine separation and desalination have focused on filter media, membranes, ion exchange, electrodialysis, and distillation.

Approximately half of the world's installed desalination capacity is in reverse osmosis plants. Reverse osmosis (RO) desalination is done using a membrane separating brine from product water. High pressure on brine causes low salinity water to permeate through to the other side of the membrane.

The applied pressure in reverse osmosis is sufficient to overcome the osmotic pressure at the given concentration of salts in the brine. Higher salinity requires higher pressure. Brackish water reverse osmosis pressure is between 17 and 27 bar (one bar is one times the atmospheric pressure, 10^5 Pa or 10^5 N/m^2, which in English units is 14.7 pounds per square inch). Seawater operating pressure is between 52 and 60 bar, typically about 1000 psi in English units. Desalting seawater is 3 to 5 times more expensive than desalting brackish water, which is twice as expensive as ordinary municipal drinking water treatment. For potable water, the target is total dissolved solids (TDS) of less than 500 parts per million (ppm).

The disadvantages of reverse osmosis are: (1) the energy required for operating pressure, (2) the necessity of extensive pretreatment upstream of the membrane, (3) costs and downtime due to membrane fouling, and (4) a voluminous stream of reject brine that pollutes the environment. RO reject brine is classified as industrial waste by the US Environmental Protection Agency. Dewatering the RO reject brine using reverse osmosis would require very high pressure because of the very high osmotic pressure that must be overcome, therefore this solution is prohibitively expensive. Dumping or hiding the reject brine is not a solution.

An example of the unsolved problem posed by the voluminous stream of RO reject brine is the largest reverse osmosis plant in the United States, the Yuma Desalting Plant. This expensive modern facility has been idle since a 6-month test period ending in 1993 because dumping of its voluminous 9,400 ppm RO reject brine stream proved environmentally unacceptable. If operated at full capacity, with feed of saline agricultural drainage water (TDS 2,900 ppm) from the Wellton Mohawk Valley of approximately 390 million liters (102.7 million gallons) per day, the Yuma Desalting Plant could produce about 275 million liters (72.4 million gallons) of desalted water per day. The Yuma reject brine stream (TDS 9,400 ppm) is a daunting 117 million liters, or 117,000 m^3 per day. Although the waste brine is relatively low in salinity, over time the salts accumulate where it is dumped, poisoning local fauna and creating a putrid trap for migrating waterfowl. From this example it should be clear that concentration of RO reject brine is an important unsolved problem in the art of desalination and a critical need for environmental protection as humanity struggles to increase the water supply.

Seawater salinity is approximately 35,000 ppm. Most of the salt is sodium chloride, but calcium carbonate and sulfate salts are also present in high concentrations, and these other salts are what cause scale, an insulating crust on heat exchange surfaces, making distillation difficult. These scale-producing salts also block reverse osmosis membranes, so a necessary step is pretreating the brine upstream of the membrane.

Various physical water treatment devices and processes use electromagnetic force in combination with flow velocity to cause Lorentz force on ions in the feedwater. Laminar flow is considered to be good, because turbulent flow would remix the ions. However, because Lorentz force is proportional to flow velocity, and laminar flow must be slow, prior art in this area has significant limitations.

Getting potable water from seawater is much more challenging for reverse osmosis than the Yuma reject brine (TDS 9,700). The energy requirement is very large, due to the high pressure required. RO desalination of seawater has a typical recovery rate of only 50% , so the reject brine would have a salinity of approximately 70,000 ppm, or 7%, and it would be as voluminous a stream as the stream of potable water produced. Dumping such a voluminous stream of highly concentrated industrial waste is not a long-term option in a world with rapidly increasing water needs. A high salinity plume dumped into the ocean is not a sustainable solution because no one wants a local Dead Sea. Various proposals for hiding the waste stream underground or in the ocean have transportation problems and are not really solutions at all.

The only known dewatering method to reduce the volume of reject brine is evaporation ponds, which require valuable space and blight the environment near production facilities. Evaporation ponds are a toxic trap for migrating waterfowl. Industrial waste dumpsites, even temporary ones, are not satisfactory solutions to the unsolved problem of reject brine from reverse osmosis.

Another major cause of environmental blight is oil and natural gas wells, which produce 20 to 30 billion barrels of brine each year. This water ranges in salinity from a few thousand to 463,000 ppm. The volume is 70 times the total of all liquid hazardous wastes generated in the U.S. Approximately 95% of this brine is reinjected, at least by responsible operators, but that still leaves a huge stream being dumped into evaporation ponds. A need exists for a better way than evaporation ponds to concentrate produced brine from oil and gas wells. A need also exists for a better way to do electromagnetic oil-brine separation.

Radial Counterflow Inductive Desalination

Simultaneous source-sink flow, or radial counterflow, is driven by a centrifugal pump made up of two counter-rotating disks with a tree of induced vortices between them. A radially outward source flow of brine goes into a shrouding tank and concentrates, while a radially inward sink flow of fresh water flows inward for extraction by an axial pump. The convergent sink flow passes under an inductor on its way to the axial exhaust port. The viscosity and inductive repulsion caused by the inductor hinder the passage of brine in the sink flow, so only fresh water can reach the axial exhaust port.

Crystallization of the scale-forming salts that remain is aided by Joule heating from the inductor. Solvent and gases are continuously axially extracted in sink flow, favoring crystallization. Sodium chloride is cooled and crystallized in the shrouding tank. Brine comprising other salts flows out of the tank to treatment by suitable means. Thus brine is separated into fresh water, crystallized salt, and concentrated brine. Oil also is separated from brine. Metal recovery is another application, using the teacup effect, inductive repulsion, and grooved runners on the casing and the disk surfaces to separate metals from light solids and water.

Tiny centrifugal separation effects of innumerable turbulent eddy vortices are integrated by the forcing regime of the centrifugal pump and the axial pump. A coherent network of organized low pressure gradients along capillary and arterial vortices gives bulk porosity so that the sink flow can go through the source flow, with the radial vortices provide arterial conduits for a sink flow of fresh water and gases to axial extraction.

Components

Radial counterflow within a casing is caused by a centrifugal pump and an axial pump. The centrifugal pump, made up of two counter-rotating disks, advects brine radially outward, and back pressure in combination with the suction of an axial pump advects fresh water radially inward to axial extraction. A baffle separates the radially outward source flow from the radially inward sink flow. Source flow is divergent, and sink flow is convergent. Sink flow is between the casing and the rotating, shearing baffle.

A pancake coil inductor causes wall-normal force advecting brine away from the casing and into a boundary layer against the baffle. Induced viscosity in brine impedes its sink flow, but fresh water slips through. Runners on the baffle advect the brine away from axial extraction. What flows through an axial exhaust port is water of reduced salinity. What concentrates in a shrouding tank surrounding the centrifugal pump is concentrated brine. Agitation and continuous axial extraction of gases and solvent accelerates crystallization in the shrouding tank. High shear between the counter-rotating disks creates a network of turbulent vortices in the brine, each of which, large or small, performs centrifugal separation. Fresh water concentrates at the vortex axes; concentrated solids grind together in shells at vortex peripheries. Back pressure from the shrouding tank and the suction of the axial pump advect fresh water along the vortex axes in an inward sink flow that penetrates the bulk of the source flow brine. The inductor strips off the conductive shells of the vortices from the converging sink flow. The microscopic separation effects of the turbulent vortices are collected by the forcing regime of the centrifugal pump, axial pump, and inductor.

Osmotic pressure is overcome by focused advection along the axes of turbulent vortices, driven by back pressure and by axial suction. Turbulence, together with the driving forces which organize it, give the bulk feed an effective porosity, acting as a filter, allowing fresh water to converge to axial extraction while brine is excluded by its conductivity and by its density.

Axial extraction of solvent (fresh water) supersaturates the brine, which collects in the shrouding tank. Concentration, agitation, Joule heating from the inductor, and continuous axial extraction of solvent and gas during crystallization all provide favorable conditions for nucleation and secondary crystallization of calcium carbonate and sulfate scale. Cooling means at the tank wall assist in the crystallization of sodium chloride. Solids and a concentrated brine stream of other salts then flows from the tank.

Metal recovery from pit water, slurry, or industrial wastewater is practiced in the same device. Grooved runners in the centrifugal pump trap metal particles, and the repulsive force of the inductor flushes the particles out of the grooves into a sink flow within the casing. Lighter solids and oils proceed radially out, and metal is axially extracted below the baffle.

Examples of feedwater are reverse osmosis reject brine, seawater, boiler water, industrial wastewater, pit water, slurry, or produced brine from oil and gas wells. No pretreatment of the feedwater is necessary, and high salinity is no problem. Separation and crystallization is continuous, in a low tech device having high power efficiency.

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