Vorsana™

RADIAL COUNTERFLOW SOLUTIONS

Tri-Phase Separator

US Patent 7757866, filed Dec. 20, 2007, issued July 20, 2010
Title “Rotary Annular Crossflow Filter, Degasser, and Sludge Thickener”
International PCT Application No. PCT/US08/85916 filed Dec. 8, 2008, currently pending in Australia, Brazil, Canada, China, India, Korea, Mexico and the EPO.
Wilmot H. McCutchen, Inventor

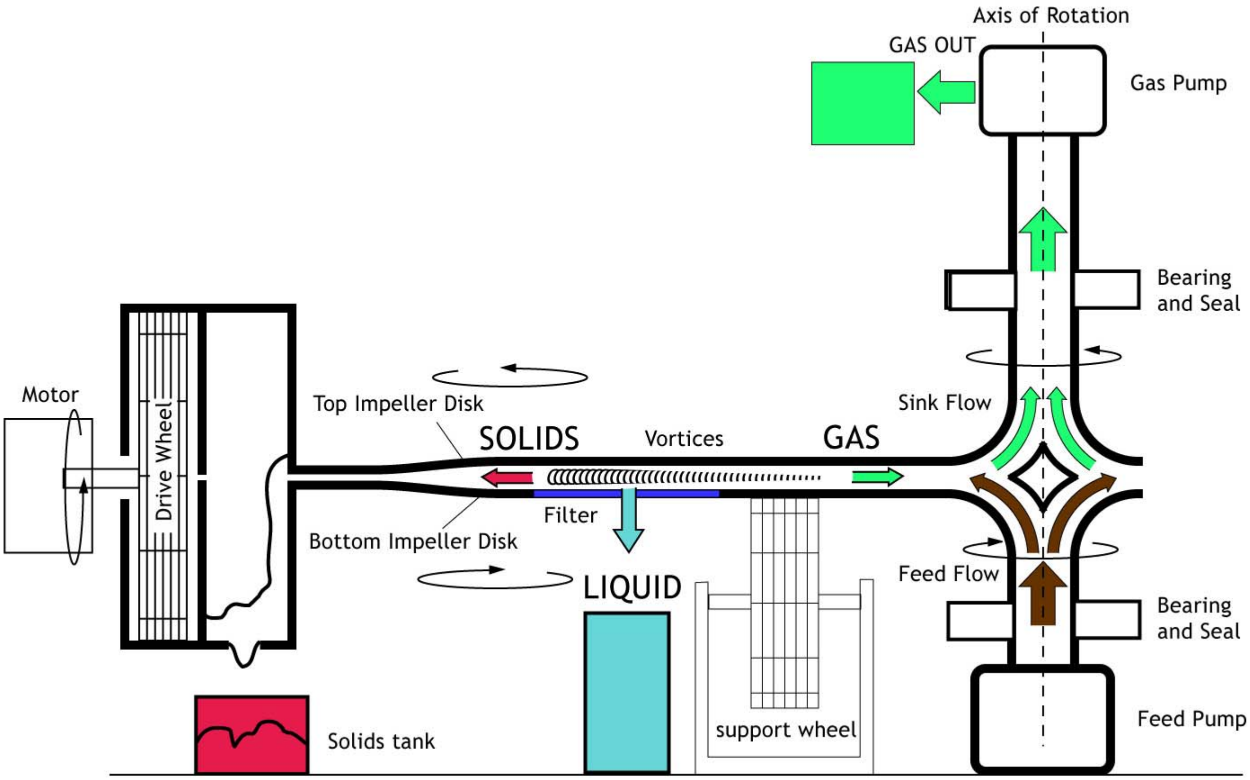
A Continuous Three Phase Separator of Gases, Liquids and Solids

The Vorsana Tri-Phase Separator, a variant of the McCutchen Processor™, performs continuous three-way separation of gas, fluids and solids in a one-pass process using a simple mechanical device, without added heat or chemicals or dead-end filters. It represents an inexpensive and easily scalable improvement in industrial and municipal wastewater processing, cleaning of brine waste from oil and gas production, field water purification, and food and beverage processing.

Summary

In the Vorsana Tri-Phase Separator, a rotating annular crossflow filter shears and separates a fluid mixture between counter-rotating coaxial centrifugal disk impellers. An axial feed of the fluid mixture flows outward between the disks, where the action of the oppositely rotating disk impellers creates a working zone of extreme turbulence organized into rapid vortices. A constriction at the disk impeller periphery slows the radially outward flow and increases the residence time of the feed in the working zone. Solids are spun out of the vortices and collect by centrifugation at the impeller periphery, where they thicken into a sludge and are extruded. Fluids exit through a filter surface inset into the bottom impeller, where shear lift ejects solids from the filter surface and keeps the filter clear. Gases, oils, floating solids, and fractions having a specific gravity less than water evolve into radial vortices where centrifugal force separates them by weight. The lightest fractions evolve into the cores of the vortices, where they are sucked radially inward and out from between the impellers by an axial pump. In this way, gases, fluids and solids are separated continuously in one pass through a simple mechanical device.

Opposing corrugated portions of the counter-rotating impeller surfaces cause audio frequency pressure pulses. At the impeller periphery, the pressure pulses milk the liquid out of sludge. At the inner portion of the radial passage prior to the filter, pressure pulses evolve gases and cause cavitation bubbles. The degassing of the high energy cavitation bubbles between the impellers removes the cushion of noncondensibles which would otherwise absorb energy on compression, therefore the implosion of the cavitation bubbles becomes extremely violent, and a barrage of high pressure pulses and ultraviolet light pulses inactivates microbes.



Schematic cross section of half of disk assembly, showing three-phase separation

Definitions of Gases, Liquids and Solids

Gases may include condensible vapors from volatile organic compounds (VOCs) or solvents, as well as noncondensible gases such as oxygen, hydrogen sulfide, chlorine, nitrous oxide, methane, and carbon dioxide. Gases in this discussion will also be defined as liquid hydrocarbons having a specific gravity less than water, such as gasoline and olive oil. Liquids may include potable water, brine, oil, juice, beer, wine, and process water. Solids may include clay, mud, suspended solids from flue gas wet scrubbing, precipitate, scale, aliphatic compounds, metal particles, yeast, crushed grapes, seeds, stems, algae, blood cells, and microbes.

Example Applications

Some examples of the many applications of this invention for the energy industry include:

1. Processing slurries from flue gas scrubbing to produce a dewatered thick sludge and accelerate the scrubbing reaction by axially extracting product gases.
2. Processing of brine produced by oil and gas operations, to separate sand, tar, drilling mud, and aliphatic oils and to recover gasoline from brine at the wellhead.
3. Treatment of Bayer process red mud from mining and smelting operations.
4. Processing of slurry from coal mining, to recover particulate coal and clean the water of mercury, aromatic and volatile organic compounds.
5. Purification of river or pond water contaminated by hydrogen sulfide, methane, chlorine, fecal matter, gasoline, oils, VOCs, amoebas, worms, mud, algae, or microbes, so as to produce potable water, in a field purification unit which can be even be run by human or animal power.
6. Dewatering and concentration of nuclear waste.

Current Phase Separation Problems

Three way phase separation problems are found in many places. One example of a need for three-way phase separation is in coal power plants, for treatment of the effluent from the wet scrubbing of flue gas used to capture sulfur dioxide and fly ash. Sulfur dioxide produces acid rain, and there are strict limits on emissions. Conventionally, removal of sulfur dioxide from flue gas is done by spraying a limestone and water mixture into the flue gas. Limestone reacts with sulfur dioxide dissolved in the water to form carbon dioxide and a gypsum slurry. The reaction depends on contact of the reagents, and SO_2 is in low concentration (less that 1%), so the spray must be retained in voluminous ponds or settlement tanks while the reactions continue and gypsum forms and settles. Settlement by gravity takes a long time, requires a large footprint, and still leaves a voluminous cloudy stratum of fine solids which are too small to settle compactly by gravity.

Another need for three-way separation is for processing industrial wastewater from machining operations. Cutting fluids, oils, solvents, metal particles, rust, dirt, and various pollutants need to be separated from the wastewater, preferably allowing the water in the effluent to be recycled through the plant. The presence of oils complicates the separation task because oils retard settlement of the solids and blind dead end filters. Volatile organic compounds such as solvents in the effluent also need to be separated from the water. In this case, three phase separation divides the effluent into three divergent streams: recoverable or easily disposable solids, recyclable water, and a light fraction stream of oils and solvents.

Municipal wastewater also requires three way phase separation to produce three divergent streams: thickened sludge, water, and a light fraction stream of oils, suds, VOCs, and noncondensible gases. The water in so-called wastewater is really a potential resource which may be recovered for use. The solids phase includes fecal matter, bacteria, amoebas, dirt, metals, tar, and a wide variety of suspended solids, and it should also be thickened as well as separated. The light fraction stream includes mercury vapor, vapor or condensate of volatile organic compounds (VOCs) including cyanide, oils, emulsions, and soap suds. The light fraction stream also includes noncondensible gases, including hydrogen sulfide (H_2S, commonly known as sewer gas), dissolved residual chlorine (Cl_2) from chlorination, methane (CH_4), nitrous oxide (N_2O), and nitrogen (N_2) from denitrification. The light fraction stream should be captured rather than dumped into the atmosphere.

Methane is of special concern for wastewater treatment plants because it is a potent greenhouse gas, 23 times more potent than carbon dioxide, and because its capture and combustion in power generators increases the energy efficiency of the plant. Another reason to extract methane from wastewater is that methane combines with ammonia in wastewater to form hydrocyanic acid (also known as prussic acid, the Nazi poison Zyklon B). Commercially, this is known as the BMA process.

Cyanide is the anion CN-. In water, the cyanide anion becomes hydrogen cyanide (HCN). The boiling point of hydrogen cyanide is 26^{o} C, which makes it highly volatile, i.e. it can be separated from water by low pressure, which causes HCN to become a gas. HCN has a density of 0.687 g/cm^3, which is much less dense than water, and therefore HCN can be separated from water by density as well as by volatility. Other cyanide compounds are: cyanogen (NCCN), which becomes hydrogen cyanide (HCN) in water, and has a boiling point of -20.7^{o} C; cyanogen chloride (13.8^{o} C); and acetone cyanohydrin (82^{o} C). Note that all of these have lower boiling points than water (100^{o} C), i.e. they are volatile organic compounds. All cyanide species are considered to be acute hazardous materials and have therefore been designated as P-Class hazardous wastes. The remediation target for cyanide in wastewater is 1:g/L (one part per billion), which is unattainable with presently known treatment technologies, even ultrafiltration, which at best can get to 10:g/L and are prohibitively expensive.

Other noxious volatile organic compounds (VOCs) in municipal and industrial wastewater are benzene, toluene, and xylene; collectively, these are referred to as BTX. Like cyanide, these are much more volatile than water, have lower viscosity, and have lower density (approximately 0.87 g/cm^3 compared to water which is 1 g/cm^3). VOCs are very potent greenhouse gases and should be captured rather than vented to the atmosphere.

Dissolved dinitrogen gas (N_2) causes algae bloom and fish die-off downstream, as well as “blue baby”syndrome in humans. Nitrogen gas in municipal wastewater comes from microbial decomposition of waste, and denitrification of wastewater so as to extract nitrogen gas is an important step in treatment. Dinitrogen gas is harmless in the atmosphere, but nitrous oxide (N_2O) is a very potent greenhouse gas, 296 times worse than carbon dioxide.

Settlement of sewage in ponds is slow and cannot remove fine solids. Sewage ponds are large stagnant toxic traps for waterfowl. Wasted space and long residence time are other disadvantages of pond settlement. Methane (from anaerobic processes), nitrous oxide, and carbon dioxide (from aerobic processes) emissions from municipal waste settlement ponds contribute to the global climate change problem.

The sludge produced by sewage settlement is still very wet. Sludge thickening in municipal wastewater plants, or other facilities, is conventionally practiced by drying, which requires heat from fossil fuels and contributes significantly to the energy load of the plant.

Crossflow Filters and Shear Thickening

Shear thickening is a phenomenon in rheology where a fluid stiffens when suddenly sheared. Water is not shear thickening, but rather is, like most fluids, Newtonian, i.e. the dynamic viscosity of water is independent of shear rate. An example of a shear thickening fluid is wet sand, which can support a car driven over it, but cannot support a car parked on it. Clay slurries, fly ash slurries, and gypsum slurries are also shear thickening fluids. Such non-Newtonian fluids are called by various names, including dilatant or rheopectic. As disclosed in this invention, shear in periodic pulses can also dewater sludges, which is another mechanism for shear thickening.

Crossflow filters avoid the principal disadvantage of dead end filters, which is blinding of the filter medium by accumulated solids. Filter blinding requires downtime and expense for replacing or cleaning the filters. Devices having rapidly moving filter surfaces are called high shear crossflow filters because their mechanically driven shear rate (>100,000 sec^{-1}) is in excess of the limit (~ 10,000 sec^{-1}) of what is possible using crossflow due to pressure driven feed velocity across the filter medium. High shear crossflow filters causes a shear lift force, which advects suspended solids away from the filter medium.

Past approaches to high shear crossflow filters include a cylindrical tank containing a plurality of hollow filter disks mounted on a rotating hollow shaft, with a feed peripheral to the disks and filtrate flow through the interior of the disks to the hollow shaft. Viscous diffusion of momentum from the spinning disks produces an envelope of water purified by shear lift force, which is squeezed by feed pressure through the disk membranes into the disk interiors and the shaft bore. The disks have small radii, therefore the multiple disk assembly must be rotated at a high angular velocity (>1000 rpm) to achieve a high shear rate for producing sufficient separatory shear lift force.

High angular velocity devices such as the multidisk rotary crossflow filter, wherein the rotor and its adherent envelope of spinning water is of variable mass due to variable fluid flow, present difficult engineering challenges and dangers. A problem with all centrifuges is wobble due to axial instability in a rapidly rotating device. An example is the spin cycle on a washing machine, where if the clothes are not evenly distributed around the axis of rotation the spinning causes wobble and the machine shuts down to avoid catastrophe. Where the centrifuge radius is small, accurate mass distribution about the axis of rotation is important to prevent wobble at high speeds. Another difficulty of multidisk rotary microfilters is the centrifugal concentration of filter-blinding oils in the envelope.

Field purification of drinking water is conventionally practiced by adding chemicals to pretreat the feed and then filtering the treated feed through a very small pore membrane under very high pressure (reverse osmosis, also known as ultrafiltration). Chemicals are necessary to disinfect the feed and to eliminate scale-forming compounds such as calcium carbonate. Reverse osmosis is expensive due to: (1) high energy consumption in generating the high pressure, (2) complicated and expensive pretreatment, and (3) the need for downtime and expensive component replacement when the small pore membranes inevitably clog from precipitated scale, oils, and particles. Although there is some crossflow over the membrane due to feed pressure, the shear rate is relatively small compared to the rotary microfilter because the feed velocity is much smaller than the spinning disk tangential velocity. The feed velocity is inadequate to sweep accumulated solids off of the membrane. Rotating or vibrating long and narrow cylindrical reverse osmosis membranes by mechanical means would improve the shear rate somewhat but might rip the delicate membranes by shear stress or cavitation damage. Also, rotation of a small diameter cylinder at a reasonably safe angular velocity can produce only a small tangential velocity at the membrane and therefore a small shear lift force.

As a solution to the critical need in developing countries for potable water, reverse osmosis field purification is ultimately unsatisfactory because of its high energy consumption and its technical complexity. Chemicals and replacement membranes are expensive and may not be reliably available through existing distribution channels, particularly in remote locations. Maintenance requires a technological infrastructure which is not present. There is a long felt but unmet need for simple mechanical means for three way phase separation to produce potable water from feed contaminated by microbes, mud, algae, worms, snails, bacteria, waste material, foul smelling gases, and oil.

Dewatering nuclear waste is also an important separation application. The best means presently known to the art is multidisk rotary microfiltration through sintered stainless filters, following chemical pre-treatment.

It is obvious that a need exists for a new approach to solving these problems.

The Vorsana Tri-Phase Separator– A Rotary Annular Crossflow Filter, Degasser, and Sludge Thickener

Counter-rotating coaxial centrifugal impellers, fed at their axis of rotation, continuously and simultaneously separate a feed into three streams: (1) solids in a shear-thickened sludge extruded at the periphery of the impellers, (2) evolved gas, oils and other light fractions extracted at the impeller axis of rotation, and (3) liquid squeezed through an annular high shear radial crossflow filter in at least one of the impellers. High volume, high turbidity feed streams can be processed in a simple mechanical device without chemical pretreatment and without filter clogging. High shear lift force expels suspended solids from the boundary layer against the annular high shear filter, and radial flow of feed over the boundary layer sweeps away the expelled solids.

The annular high shear crossflow filter shears the feed in a plane parallel to the radially outward feed flow between the impellers. Dynamically rejected suspended solids are centrifugated by both impellers to the impeller periphery and agglomerated in high turbulence. At the periphery, a concentrated slurry is sheared between closely spaced corrugated surfaces so as to form a thick sludge. Liquid is ejected from the periphery by back pressure due to the vortex-wall interaction of radial vortices with the peripheral impedance, and eventually recirculates to the boundary layer against the rotating disk filter. Back pressure due to impeller rotation squeezes the boundary layer through the radial crossflow filter to produce a clarified and degassed filtrate.

Radial vortices in the feed flow between the centrifugal impellers provide sink flow conduits through the feed for continuous extraction of evolved gases, which are sucked out from between the impellers by an axial pump drawing a vacuum at the impeller axis of rotation. Oils, VOC vapors, and other light fractions are also drawn through the radial vortices radially inward and axially extracted, while feed flows radially outward.

Implosion of audio frequency resonant cavitation bubbles destroys microbes and crushes fruits. The cavitation bubbles are not cushioned by evolved noncondensible gases because noncondensibles are axially extracted through the radial vortices. Therefore cavitation bubble collapse becomes very energetic, causing rupture of cell walls by locally generated high pressure pulses and irradiation by locally generated ultraviolet light pulses.

Patent Illustrations

Figure 1 shows a cross-sectional schematic view of part of the preferred design, comprising counter-rotating centrifugal impellers, one of which comprises a high shear crossflow filter.

Figure 2 shows a cross-sectional schematic view of the remainder of the preferred design, showing the drive means for producing counter-rotation of the impellers.

Figure 3 shows a bottom view of the bottom impeller and its annular high shear crossflow filter.

Figures 4a and 4b show a detail cross section of opposed corrugated portions of impeller surfaces as the impellers counter-rotate.

Figures 5a, 5b, and 5c explain the vortex-wall interaction.

Figure 6 shows a cross-sectional schematic view of an alternative design, comprising a single impeller opposed to a static top casing.

Figure 7a and 7b show details of fluid flow next to the filter, and the shear lift force.

Sept. 23, 2010

Contact: David McCutchen
david@vorsana.com

www.vorsana.com