Vorsana™

Vorsana Steam Stripper

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"Radial Counterflow Steam Stripper"

US Patent application 12/345,324 filed December 29, 2008

International PCT/US2008/088579 national filing in China.

A Thermal Separator

A simple and scalable processor for continuous thermal separation that improves the efficiency of power plants and minimizes water waste. Exhaust steam is sheared by counter-rotating axially fed radial flow disk turbines, causing low enthalpy steam to separate from high enthalpy steam. The dry low enthalpy steam (the slow tail of the Maxwell speed distribution) goes inward to the condenser. The high enthalpy steam does work turning the radial flow turbines as it moves outward, losing enthalpy and condensing. The condensate goes radially outward with the high enthalpy steam while the low enthalpy steam goes radially inward to a condenser. Similarly, cooling water is evaporatively cooled without cooling towers with counter-rotating centrifugal pumps advecting water radially outward while the suction of a condenser draws vapor radially inward.

Overview

Turbine exhaust steam is axially fed between counter-rotating radial flow disk turbines, separating into: (1) a radially inward flow of low enthalpy dry steam, and (2) a radially outward flow of high enthalpy steam, noncondensibles, and condensate. The radially inward flow goes to a conventional condenser. The radially outward flow loses enthalpy turning the disk turbines as it passes in the boundary layers against the disks, thus becoming low enthalpy dry steam, and the counter-rotation of the disks by impinging mass flow of condensate, high enthalpy steam, and noncondensibles sustains a cascade of dynamic vortex tubes in the shear layer between the boundary layers. The low enthalpy dry steam resulting from work being done flows inward into the condenser through the vortex cores in a network of fractal turbulence. Condensate exits the periphery of the workspace, ready to be pumped back into the Rankine cycle. More condensate is recovered from the low enthalpy vapor in the condenser. Heat rejection from the cooling water circuit is easier because the significant mass fraction of high enthalpy steam does not enter the condenser.

The same approach can be used for cooling water. Cooling water is fed between the disk turbines at their common axis of rotation, and a fractal network of vortex turbulence between the disk turbines organizes dynamic evaporative cooling. Chilled water flows radially outward to recirculation, and hot water and vapor flows radially inward to the impeller axis of rotation.. Vapor is stripped through the vortex cores of fractal turbulence into a condenser where it condenses as distilled water. The ultimate heat rejection is directly into the environment, without discharge of vapor, thereby conserving water.

Water and Energy Waste at Thermal Power Plants

The thermal efficiency of a modern steam power plant is usually only ~ 35%. Most of the energy in its fuel is wasted. Inefficiency is principally due to heat rejection in the cooling tower, where waste heat from the steam turbine exhaust is dumped into the atmosphere as latent heat in the vapor of cooling water.

The vapor out of the cooling tower is wasted water as well as wasted energy. Fresh water used for thermal power plant cooling water is becoming a precious commodity, forcing a choice between water for power and water for people. The amount of water wasted by conventional thermal power plants is enormous. The United States Geological Survey (USGS) estimates that thermoelectric power generation requires 3.6×10^{10} cubic meters (m^3), or 136 billion gallons, of fresh water per day. In the year 2000, that was 39% of freshwater withdrawals in the United States, slightly less than agricultural irrigation (40%), and much more than other industrial and residential use.

A need exists for a better way of condensing exhaust steam, avoiding the water and energy waste of cooling towers and conventional steam condensing.

Turbine Exhaust Steam

Power plant turbine exhaust steam is wet, i.e. it has a high weight percentage of condensate. Turbine blade erosion concerns place a lower limit on quality (weight percent of vapor) of 0.88, with most turbines operating in the 0.90 - 0.95 range. Exhaust steam still has high energy content, or enthalpy (kJ/kg), even after doing work in the turbine, but its energy is principally in latent heat of condensation (h_{fg}). The latent heat must be extracted so that the water can condense and be pumped back into the boiler to be re-used in the Rankine cycle.

Mass flow through a steam turbine is pushed by the high pressure of the boiler and simultaneously pulled by the low pressure of a steam condenser. Condensation of vapor in the steam condenser creates a vacuum (typically 0.03 - 0.4 bar) which pulls more steam through the turbine.

The conventional steam condenser (surface condenser) comprises a shell and tubes disposed within the shell. The tubes are part of a cooling water circuit. Turbine exhaust steam is injected into the shell, and cooling water circulating through the tubes bears off the waste heat to the cooling tower. The condensate drips into a hotwell and is pumped back into the boiler. The cooling water is sprayed into a cooling tower, where evaporative cooling rejects the turbine exhaust waste heat into the atmosphere. Vapor out of the cooling tower is wasted water. The water volume in the cooling water circuit must be replenished by make-up water, which must be carefully pre-treated to prevent scaling and biofouling within the tubes.

Re-use of the cooling water and its continuous evaporation concentrates the dissolved solids, so periodically some blow-down is discharged to purge the system. Evaporation builds up a high concentration of limestone (calcium carbonate, $CaCO_3$), sulfates, and other scale-forming compounds in the cooling water. Scale is a tough and insulating crust which is precipitated by heat on the interior walls of the tubes. The blow-down has a high percentage of total dissolved solids and is a water pollution problem as well as a waste of a precious resource.

A steam ejector communicating with the shell purges any noncondensible gases and also helps to maintain a very low pressure in the shell. Low pressure in the condenser is key to optimal Rankine cycle efficiency.

Cooling Towers

The waste heat absorbed by the cooling water of the shell and tube surface condenser could be discharged immediately by dumping the cooling water into the environment (the once-through process), but this option is not favored because thermal pollution of the environment is usually not acceptable. Air cooling is another option, but for large power plants it is not satisfactory because of the low heat flux between fins and ambient air, even when the air is blown. When the heat load is large and the ambient air is hot, such as on a hot summer day when many air conditioners are running, air cooling may fail.

The preferred method for reliable heat rejection is to extract the heat load by evaporative cooling in order that the cooling water can be recycled through the tubes. The conventional evaporative cooling method involves a cooling tower. Within the cooling tower, an updraft of air meets a spray of hot cooling water, and evaporation cools the spray. Typically 3 - 6% of cooling water sprayed in is lost by evaporation in the cooling tower, a large waste of water as well as energy. In a typical 700 MW coal-fired power plant, having a circulation rate of 71,600 m^3/hr, the water waste is 3,600 cubic meters an hour.

Nuclear and gas plants also waste water in heat rejection from their steam turbine exhaust, no less than coal plants. A major siting constraint on nuclear plants is the scarcity of fresh water. Of course, seawater or alkaline water won't work for a cooling water circuit because it contains scale-forming dissolved solids which precipitate at high temperatures and would quickly clog the tubes.

Petroleum refineries have very large cooling water systems. A typical large refinery processing 40,000 metric tons of crude oil per day (~300,000 barrels per day) circulates about 80,000 cubic meters of water per hour through its cooling tower system, evaporating and wasting a prodigious amount of precious fresh water. Dumping vapor in the atmosphere is not a sustainable practice, and a need exists for an alternative method for heat rejection which does not waste water.

Another reason, besides water waste, to eliminate cooling towers is the danger they pose to public health. The warm, moist environment in a cooling tower provides a favorable habitat for the Legionella bacteria that cause Legionellosis, a type of pneumonia commonly known as Legionnaire’s disease. Studies have shown that 40 to 60% of cooling towers are infected with Legionella. Entrained infected mist droplets in the drift out of the stack provide transportation for these bacteria to contact with humans kilometers away. Each year in the United States, 8,000

- 18,000 people are infected. Therefore biocidal treatment is necessary, and there is strict regulatory scrutiny.

Infected steam billowing from cooling towers is a visible threat to the health of the community. Public acceptance of the presence of power plants is an important consideration in siting. Cooling towers, whose profile is associated with the nuclear disaster at Three Mile Island, and which emit huge volumes of what looks like smoke, are not good for public relations. They are a prominent and objectionable feature of any power plant. Now that fresh water has become a scarce resource, coal, gas, and nuclear power plants have a need for an alternative to cooling towers.

The Ranque-Hilsch Vortex Tube

The vortex tube is an axial counterflow device having no moving parts, where the feed pressure drives thermal separation into a cold stream and a hot stream. See Ranque, U.S. Pat. 1,952,281 (1934). The length of a vortex tube is typically between 30 - 50 tube diameters. How thermal separation occurs in a vortex tube has not been settled, and interesting speculation abounds. See Chengming Gao, *Experimental Study on the Ranque-Hilsch Vortex Tube* (Eindhoven 2005) http://alexandria.tue.nl/extra2/200513271.pdf.

In operation, a tangential feed nozzle at a cold end of the vortex tube jets in a pressurized gas feed which swirls along the tube to a conical impedance partially blocking the opposite end, the hot end. The conical impedance is a valve pointing toward the cold end, and there is a passage around the conical impedance where the hot stream exits at a higher temperature and lower pressure than the feed. A cold stream rebounds from the conical impedance in an axial jet inside the feed vortex and exits the cold end at a lower temperature and lower pressure than the feed. Thus a hot stream and a cold stream are separated from a feed stream, both at lower pressure. Feed pressure drives thermal separation in a very simple and easily scalable device. Commercial applications of the vortex tube include spot cooling for welding and machining operations.

Cascading of vortex tubes has the problem of reduced feed pressure at each successive stage of the cascade, with consequent loss of separation, unless there is some boosting of feed pressure between stages. The Vorsana Steam Stripper provides a way for inter-stage boosting in multiscale cascades of vortex tubes.

SUMMARY OF THE VORSANA STEAM STRIPPER

Counter-rotating spaced-apart radial flow disk turbines, fed at their common axis of rotation by turbine exhaust steam, produce a multiscale cascade of dynamic vortex tubes in the shear layer between them. In the vortex tube cascade, which is fractal turbulence, two streams are continuously separated out of the feed: (1) a stream of low enthalpy saturated vapor, which goes to a steam condenser, and (2) a stream comprising high enthalpy saturated vapor, condensate, and noncondensible gases. The high enthalpy vapor loses enthalpy doing useful work and condenses apart from the steam condenser. The steam condenser only has to extract the latent heat from a reduced mass flow of cool vapor, and is not burdened by noncondensibles and condensate. The cooling water is not burdened by the energy in the high enthalpy steam.

The cascade of dynamic vortex tubes link in a vascular network for axially extracting the low enthalpy saturated vapor (the first stream). The low enthalpy vapor flows radially inward from the fine-scale vortices into the larger scale vortices and eventually into the steam condenser, drawn along low pressure gradients established by the shear of the disk turbines and the suction of the condenser.

The second stream (high enthalpy vapor, noncondensibles, and condensate) pushes the disk turbines as it flows radially outward to the periphery of the space between them, where it emerges as condensate and noncondensibles. The work done by the high enthalpy vapor reduces its enthalpy, and the low enthalpy steam resulting from this work falls into the vortex cores and is axially extracted.

The conventional approach is to dump both the high energy molecules and the low energy molecules into the condenser, along with the condensate and noncondensibles. The Vorsana Steam Stripper strips out the low energy molecules and passes only those to the condenser, leaving the high energy molecules, condensate, and noncondensibles out of the condenser and doing useful work sustaining a radial counterflow forcing regime and even turning a generator.

The Vorsana Steam Stripper works on the turbine exhaust energy which otherwise would be totally wasted up the cooling tower. A generator may be run by connecting a peripheral drive wheel between the disks, thereby increasing the efficiency of the power plant. By pushing the disks, the high enthalpy vapor loses enthalpy and condenses, thereby reducing the load on the condenser and allowing for a more intelligent system of cooling water cooling.

The Vorsana Steam Stripper also offers a way for recycling cooling water without cooling towers. Thermal separation, to chill the cooling water and reject the waste heat from the condenser, occurs in the fractal vortex turbulence network driven by a radial counterflow forcing regime. The tree-like radial arrays of low pressure gradients between axially-fed counter-rotating impellers provide a dynamic vascular network for extracting the waste heat from the cooling water in high turbulence and transporting the vapor to a condenser, where pure water is recovered. Water is not wasted by dumping vapor into the atmosphere.

In a shear layer between the disks is an array of radial vortex trees which are fractal turbulence. Cores of fine-scale vortices communicate with the cores of larger-scale radial vortices, and so on to the axial exhaust port at the axis of rotation of the disks. In each vortex, centrifugal separation of cool water from hot water occurs due to the density difference. The cool fraction goes to a boundary layer against the disks, and the warm fraction remains in the shear layer. Momentum transfer from the disks goes preferentially into the cool water, which is advected radially outward to collection and recirculation. The disks are driven by peripheral drive wheels turning between them.

A large surface area for evaporative cooling is presented by the vascular network of vortex trees in the shear layer between the counter-rotating centrifugal impellers. The warm fraction of the cooling water, which because it is less dense collects at the vortex cores, is squeezed radially inward to the impeller axis by the vortex-wall interaction and then is opened into larger and larger vortices having vapor cores communicating with the condenser. The low pressure of the condenser causes the warm fractions to evaporate and reject their latent heat in vapor. A continuous stream of cool, low enthalpy vapor, bearing off the cooling water heat load as latent heat of evaporation, flows radially inward through the vortex cores to the disk axis of rotation and from there into the steam condenser where it is recovered as distilled water.