

The Energy Savings Potential in Closed Loop Chilled Water Systems

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Abstract:

The variable heating & cooling demands of a hospital environment accentuate all aspects of a district cooling system. Contrary to conventional thought, closed loop systems experience significant contaminant fouling and create hardships for system energy efficiency. Optimizing operation and control of the system to maximize performance relative to building load and ensuring that the condition of the chilled water and heat transfer services are effective is a successful energy initiative. System operation at peak capacities takes on more importance when the clinical and laboratory departments can be impacted. Faced with building expansions and new levels of efficiency requirements, the University of Alberta Hospital examined and experienced various control strategy and filtration alternatives to keep the recirculated water systems free of troublesome contaminants and operating efficiently. This presentation details the problems, conditions, alternatives and results of the efforts to design, fund and confirm the goal of improved system efficiency.

Key words: closed loop, energy efficiency, control strategy

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BACKGROUND

The University of Alberta Hospital / Stollery Children's Hospital is a primary tertiary care centre in Northern Alberta Canada and is situated on the campus of the University of Alberta. The Emergency Department deals with many high acuity patients with complicated medical illnesses and a wide variety of traumas. The complex has dedicated emergency services for children as well as adults. There is an active Trauma team on-site at all times, supervised by Emergency Medicine facility members. The facility has primary and secondary helicopter pads to handle the airborne transport of patients, both civilian and military. As well as containing the two hospitals, the WMC [Walter C. Mackenzie] Health Sciences Centre houses the Provincial Laboratories for Northern Alberta, including a level III lab.

The Hospitals have a total of 700 beds, the Emergency Department has 6 Trauma beds, 11 active treatment rooms, 12 general exam and 6 Observation beds.

The facility contains two active treatment MRI's and three research MRI's, as well as the most current technology in diagnostic imaging. The WMC facility was originally constructed from 1977 through 1986. Currently there is a major program of capital projects under construction to update and increase the size of the facility. The WMC is 3.3 million square feet, with another 400,000 square feet planned over the next 3 years.

Officially, the WMC opened in 1982, housing the University of Alberta Hospital and the Provincial laboratory. In 1998, construction began on the Stollery Children's hospital, which was completed in 2001.

There are eight buildings included in the University of Alberta Hospitals, The Mackenzie Centre is the main facility and makes up 80% of the total area. The majority of the Hospital operates on a continual basis, including the Mackenzie Centre and the support buildings.

The chilled water from the University of Alberta district chilled water system enters the facility at multiple points. The facility was originally supplied by two 12-inch feeds from the utility corridor serving the district chilled water system. Additional chilled water feeds have been added due to expansions of the facility. Chilled water is required not only for the facilities' primary air handlers [CACU's], but also for the clinical process loads in many areas within the facility including, diagnostic imaging, the surgical suite, intensive care units to name several clinical programs.

The University of Alberta Campus district utility system supplies the hospital with the majority of its utilities through the utility corridor that services the greater campus area. Chilled water from the cooling plant supplies approximately 100 buildings. The WMC facility represents 1/4 to 1/3 of the load of the district chilled water system.

The U of A cooling plant, which has a capacity of 28,000 tons, was constructed in phases from 1968 to 1983 and is situated on the bank of the North Saskatchewan river. To respond to load demands the plant has a number of chillers varying in size from 2,000 tons to 5,000 tons. The river is used for condensing purposes, in the winter the plant operates in free cooling mode where chilled water is produced without compressors, due to the low water temperature. All the chillers are centrifugal and all drives in the plant are electrical.

PURPOSE

After the construction of the facility was complete and the building systems were running for a number of years, facilities management noted that the Central Air Conditioning Units [CACU's] were experiencing cooling problems. Clinical and support areas served by these CACU's noted cooling difficulties, particularly on the lower levels. Operational problems with the WMC facilities process loops were also being experienced.

Over time, these problems were becoming more pronounced, specifically:

- ✔ A shortfall in the cooling capacity of the facilities air handlers.
- ✔ Failures of refrigeration equipment that serve clinical equipment by way of dedicated process loops.

In addition to these problems, we wanted to extend chilled water system capacity and optimize system performance to reduce the utilization of chilled water and increase energy efficiency. Our principal goal as we undertook this initiative was to ensure that system performance could be maintained and potentially improved. Our focus was in two areas:

- ✔ To optimize the supply / return delta temperature difference to more closely index system operation to building load.
- ✔ To remove particulate from the chilled water that could effect the performance of heat transfer surfaces.

The primary chilled water feeds to the WMC utilized 4 parallel pumps controlled by system discharge pressure. The original design incorporated a fixed pressure set point set at 775 KPa. Incoming pressure from the utility corridor was 700 KPa. A pump bypass valve connected in parallel with the supply pumps was incorporated to respond to

system load changes. The size of the bypass line size equivalent to the capacity [875 US GPM] of one of the supply pumps.

The system was operating inefficiently for a number of reasons:

- ✓ The return of chilled water to the district system at less than 12 deg C [54 deg F] increasing operating costs.
- ✓ Cycling of the chilled water supply pumps since the controller could not control the bypass valve under certain load conditions.
- ✓ Air handler [CACU] cooling coils were not operating at the required design capacities.

The particulate problem was becoming acute. The facility was experiencing failures on some of the “condensing units” serving clinical equipment. Smaller sections of piping became fouled to such an extent, adequate flow was unavailable. Component failures and replacement of piping to secondary circuits on the system were becoming necessary. This was in addition to the noted reduction in air handler [CACU] capacity.

This situation was further compounded by the common perception that there was not particulate in the chilled water system. Independent tests of the chilled water prompted by the aforementioned problems, confirmed the presence of particulate in the system. The viewpoint at the time was that there was no inorganic material in the system. Since we are billed on chilled water consumption, any shortfalls in efficiency negatively impact our utility budget.

CONCEPT

VFD's and Controls

When we assessed the operation of our system, it became apparent that we could not retain the strategy of system supply pressure control, sequencing four parallel pumps utilizing a pump bypass valve. This was the original control strategy design approach year round, even during winter when only the process loads located throughout the facility required cooling. Refer to figure 1 for a schematic of the chilled water system piping and control points.

System operation was intended to maintain a wide temperature differential [ΔT], thus maximizing system efficiency using a control strategy based on pressure control, with the design intent of matching system operation to building load. Assessment of system operation indicated we were not matching the operation of the system to the cooling load requirements of the facility. Any time the system required partial pump capacity, we

could not maintain an efficient delta T. The pump bypass approach was not working. The system was not operating efficiently as the controller was continually “searching” for the correct operating point, the pump bypass valve control scheme did not allow for stable system operation. Air handlers were struggling to meet cooling requirements, to operate efficiently we needed to consume chilled water in response to building load.

Filter

To address our second area of concern (particulate and cooling coil capacity reduction), we reviewed several options. We looked at a number of different filtration approaches from cartridge type to sand filters, each were discounted due to either capital cost, lifecycle cost (maintenance), or not being a suitable solution based on our assessment of the problem. We decided that the use of centrifugal separators would be the best option for this application, given our objectives. Our expectation was that this approach would provide benefits from not only a filtration and system maintenance perspective (which is the traditional benefit), but also could provide benefits from an energy management (cooling coil performance) perspective as well.

Since District systems offer a centralized source of chilled water, the cooling source for the building is circulated not only through our facility, but all facilities and back to the chilled water plant through the utility corridor. This means that the potential exists for the older buildings in particular to distribute particulate in the form of iron oxide to all buildings supplied by the district system. This presents the traditional challenge of particulate in control valve seats and instrumentation elements, and also the potential to negatively impact heat transfer services. Consider too that heat transfer surfaces in general, and cooling coils for air handlers specifically, have lower and varying fluid velocities and that the district cooling system’s incoming building feeds have higher velocities and larger line sizes.

Information from the coil manufacturer and our own cooling coil performance testing confirmed that we were not achieving the heat transfer based on the design cooling coil capacity. The chilled water system serving the air handlers had been designed with small cartridge filters at each cooling coil. These proved to be inefficient and in fact were not viable from a facilities management viewpoint because they would plug up quickly. The cooling coils and control valves were not being protected adequately. Independent laboratory tests confirmed the presence of particulate in the system in the form of iron oxide and other contaminants. Samples of the system piping confirmed that the same type of particulate was accumulating on the piping and coils. Particulate in suspension in the larger diameter feeds was causing problems by being deposited on the heat transfer surfaces of the system. Cooling coil performance testing confirmed that our systems were not meeting design. The suitability of the filter units was assessed from an

energy perspective to see if an energy management justification could be made on the basis of energy savings, as well as the more traditional filter efficacy viewpoint.

One of the other approaches we considered was the use of a heat exchanger to isolate our facility from the district system. This was not viable for our application as we felt we would lose 1.5 to 2.0 deg. C [3 to 3.5 deg F] across the heat exchanger and we would reduce our available capacity by up to 15%. This reduction was something that we could not afford, given our marginal capacity and the limited delta T available on chilled water systems. Our other consideration was the heat exchanger itself would require filtration to preserve the efficacy of its heat transfer surfaces, and we would still have to do something to contain the particulate generated from our own building.

We opted for the use of the centrifugal separator in a side stream configuration at 25% of total system flow.

RATIONALE

VFD's and Controls

The key point for the controls was to ensure that system operation was capable of matching the cooling load. System operation is defined as follows:

- ✔ Winter or free cooling mode – Below 10 deg C [50 deg F], we isolate from Campus and generate chilled water by way of the facilities air handlers. The system operates at a fixed differential chilled water setpoint in this mode.
- ✔ Summer or cooling mode – Above 10 deg C [50deg F]. Is able to handle both the spring and fall “ shoulder “ seasons as well as summer operation. The system differential setpoint is reset based on building load. This is done uniquely for each feed so that building load can be matched allowing the consumption of chilled water to "track" the load on the building.

Operation of the system when open to the campus chilled water system can be defined as follows:

The threshold temperature for the system is 10 deg C (50 deg F). Above that temperature, the system is “changed ” to summer cooling mode. The differential setpoint is set at a minimum value by the controller, this allows the chilled water pump to essentially “idle”, ensuring that chilled water consumption is minimal. All other distribution pumps are off-line at this point. The system will “ramp up” as building

cooling load increases, specifically the controller setpoint is increased as outside temperature increases. The VFD control increases the capacity of the pump to meet the new setpoint. Concurrent with this, the system pressure drops as the cooling coil control valves at the air handlers (CACU's) open to satisfy air system cooling requirements.

The remaining pumps will cycle on or off based on the requirements of the system and the controller output to the VFD pump. When the VFD pump is at maximum and still not meeting setpoint, the control system will turn on an additional pump after a preset time delay. The VFD drive pump will then "back off", based on the requirements of the controller and the differential setpoint. This approach allows the pumps to "track" the cooling requirements of the building, since the setpoint is indexed based on the actual load on the building.

As the outdoor temperature decreases, the setpoint decreases, and the VFD pump will back off based on the change in setpoint. Pumps will cycle off in the same manner. The VFD pump will be at minimum for a preset period, and one of the pumps will cycle off. The controller will readjust the VFD pump to once again operate at setpoint.

Filter

By way of the District Cooling system, buildings on the piping loop will have particulate entering their piping networks. Buildings will also have particulate generated internally. Both of these sources create the potential to reduce the effectiveness of heat transfer surfaces, caused by deposits of particulate. Energy savings due to a reduction in fouling. Computer simulations of cooling coils using different coil capacity reduction factors indicate that potential savings exist.

Manufacturer's data for the cooling coils confirmed that overall system energy consumption goes up significantly with the accumulation of particulate on coil surfaces. Air handler testing on site confirmed that the coils were operating at less than 80% of design for the type and vintage of cooling coils connected to the WMC chilled water system. Velocity / temperature profile testing at the cooling coils confirmed what we already knew operationally, the air handlers [CACU's] were not operating to capacity.

In considering the impact on cooling coil efficiency, we generated the following separator performance requirements for the selection of a separator to protect the system:

- ✓ Chilled water shall be fed to the centrifugal-action solids separator [refer to figure 3], rated for a flow range of 440-880 US gpm [sidestream]. System operation in spring/fall mode should allow the system to operate isolated from the District utility system, allowing the filter the opportunity to clean the WMC system. When operating open to the district system, we will be able to filter our water continually to help clean heat transfer surfaces and prevent any increased deposits. In summer, the

separator unit would in effect be filtering a portion of the incoming district water. At light to medium loads, we essentially can filter the same amount of water brought into the building. During high consumption periods, we are able to filter approximately one third of the chilled water in each feed.

- ✔ The separator shall incorporate a tangential inlet flow, creating initial centrifugal action that is accelerated into the inner separation barrel via internal, mutually tangential slots. This centrifugal action causes particles heavier than the chilled water to be forced to the perimeter of the separation chamber, where these solids drop along the perimeter and into the separator's collection chamber.
- ✔ With solids removed, the chilled water is drawn to the separator's low-pressure center vortex and upward through the outlet. Solids are continually bled from the separator and concentrated in a collection / recovery system. This allows for the removal of separated particulate without system shutdown or water loss.
- ✔ The collection / recovery system is emptied periodically and we have established a preventive maintenance program task for its inspection and the subsequent removal of the solids.

One concern that had been expressed when considering this application is that because the building is part of a District Cooling system, the project building [in this case the WMC facility] would in essence be cleaning the water on behalf of all buildings on the system. While this is true to some extent, we can also reason that based on gains in system performance, the benefits will be more pronounced at the building site with the incoming water being filtered. This is no longer an issue. After the results of the first installation we decided to proceed with the installation of our second system. Based in part by this success, the University of Alberta Utilities division has installed a number of separators in the distribution system from the cooling plant. Both organizations have been installing the units as new wings or buildings are added at both the University and the Hospital sites.

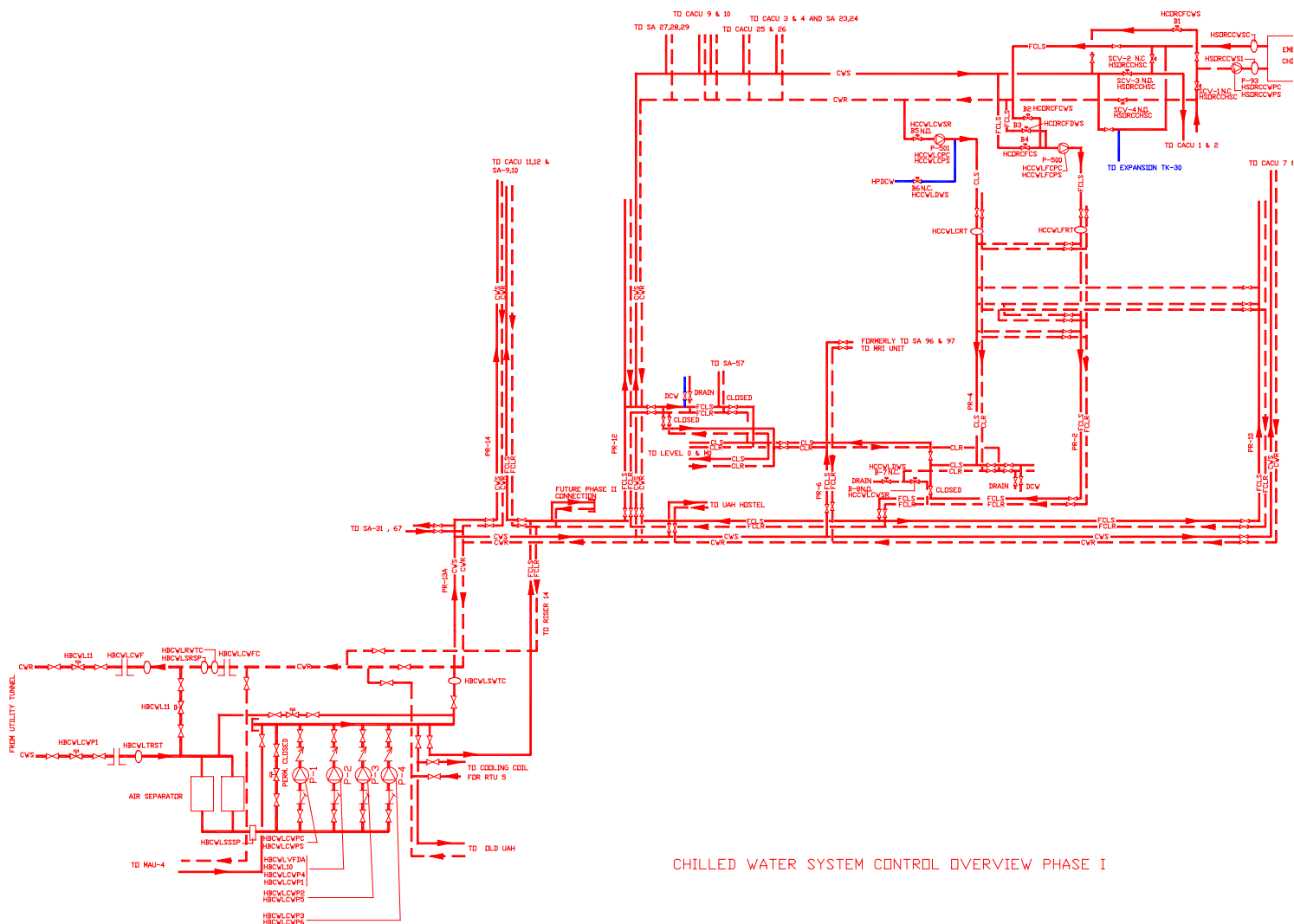
SUMMARY

Our chilled water system had been operating inefficiently. We were experiencing component failures on process loops as well as the overall issue of the air handling systems operating inefficiently.

- ✔ The incorporation of VFD drives and differential pressure control indexed to building load has proven effective in improving system performance. In combination with the utilization of distinct operational mode (where we can generate cooling through the facilities air handlers). This has provided exceptional operational savings.

Consumption reduction was 580,440 M3 between the base budget year of 1991/92 and 2000/2001. We have referenced the 2000/2001 budget year since that is the last year available for comparison prior to the addition of three new chilled water feeds to the WMC facility. Based on the current cost of chilled water this initiative is saving in excess of \$190,000 annually. Refer to figure 2.

- ✔ Based on the most recent budget year, the facilities 36 primary air handlers [CACU's] required an estimated \$600,000 in chilled water. The utility consumption for chilled water required \$750,000 last budget year. The chilled water cost is close to 10% of the \$8.5 million dollar annual utility budget.
- ✔ Building extensions have incorporated the lessons learned from this project. Three recent facility extensions including a new emergency wing and burn treatment centre have incorporated the control scheme and the use of separators on the new chilled water feeds to the WMC. Follow up cooling coil performance testing has confirmed that cooling coils are operating to design, and the control strategy is able to track the requirements of these new areas.
- ✔ The use of centrifugal separators on each incoming chilled water feed has helped maintain the cooling capacity of the heat transfer services in the facilities air handlers.
- ✔ The component problem of failures to secondary loops has been successfully addressed. Component failures on these loops, based on our PM (preventative maintenance) program data confirm that these problems have not been reoccurring. Previously, we had been experiencing regular failures and our refrigeration mechanics were advising of serious operational problems if the failures continued.
- ✔ The University of Alberta Utilities division has installed a number of separator units based in part on the results we have achieved. They have installed 6 units, they had originally used a variety of filtration schemes for filtration but have been utilizing separators since 1997.
- ✔ We have upgraded our master specification to ensure that all new building extensions and utility feeds take advantage of the results of this initiative.
- ✔ The University of Alberta Facilities Management department is now installing units on some of the new buildings being constructed on campus.



CHILLED WATER SYSTEM CONTROL OVERVIEW PHASE I

Figure 1 – Chilled water schematic

Budget year	1991/1992	1992/1993	difference	percentage
Weather [CDD]	1553.6	1508.0	45	3%
Cons. [*10/3 M3]	2140.95	1560.51	580.44	27%

580,440 M3 @ \$.33/M3 = \$191,545.20

Figure 2 – Chilled water consumption

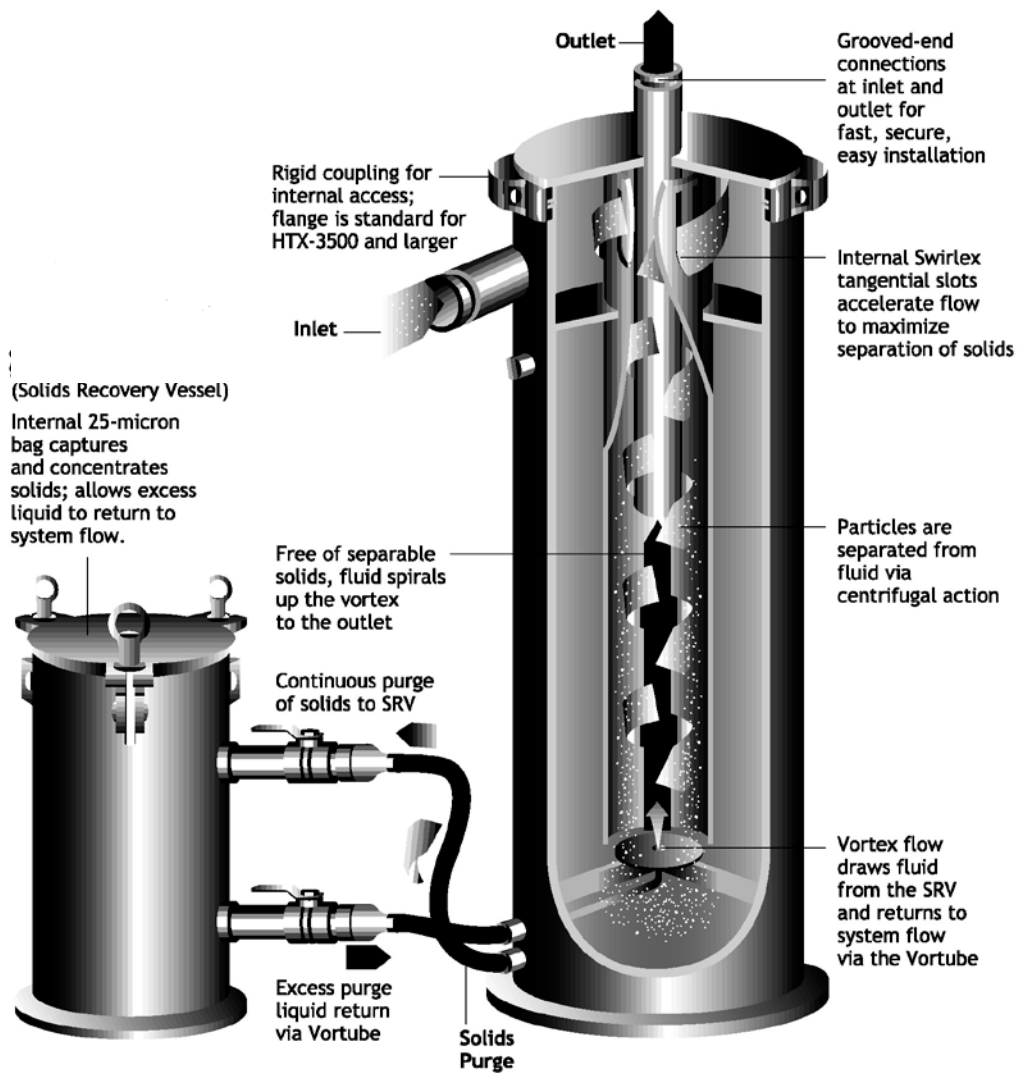


Figure 3 – Separator schematic