US NAVY

Advanced Hull Cleaning Vehicle Waste Treatment System

SpinTek*filtration*
Phase I
January, 2004

SpinTek Filtration
10851 Portal Drive
Los Alamitos, CA 90720
Phone (714) 236-9190
Fax (714) 236-9196
Internet www.spintek.com

SpinTek filtration

Table of Contents

SpinTek filtration

Introduction

The US Navy has developed a new type of Advanced Hull Cleaning Vehicle (AHCV) and the discharge from this mobile cleaner must be processed and cleaned to a level suitable for discharge to the local POTW. The secondary goal is to concentrate the solids from the wastewater as much as possible to minimize the amount of waste that must be disposed of.

The system that will treat this 50 gpm waste water stream must be robust and reliable and operate with minimal operator input. The contractors performing the hull cleaning with the AHCV must have a "plug and play" system with push button operation and minimal operator input. The process must operate with a wastewater treatment system on a consistent and reliable basis.

The physical size of the waste processing system shall be compact to reduce the needed space pier side that is already crowded with a variety of equipment, hoses, cabling, and personnel.

SpinTek has successfully demonstrated its alloy ceramic metal filter in a small scale proof of concept test (Phase I) for this application and the results are included in this report. The alloy filter has been tested in the laboratory on the actual raw waste and treated sludge in a cross flow and rotary filter configuration. We believe that this process can be successfully scaled up to meet the requirements of the AHCV and the data in this report supports that position.

SpinTek is proposing to demonstrate that an extremely rugged and durable alloy filter can process the hull waste under pier side conditions. In addition, the alloy filters are self-cleaning by back flow and/or back pulsing the filter.

A Phase II program is planned where the performance of the alloy filter in an integrated cross flow and rotary configuration be evaluated in the laboratory on larger (100 gallon +) samples of raw wastewater from the AHCV. SpinTek will test both raw feed and also on sludge that has been formed by flocculation.

The focus of Phase II will be the use of the cross flow alloy filter in an alternating cross flow configuration as a preconcentrator of the raw waste material. Subsequently the SpinTek rotary filter will take the concentrated sludge from the cross flow system and further concentrate to minimize the waste for subsequent disposal.

Other work has been performed on the sludge produced by a flocculant device and the results of those tests have been included in a separate report.

SpinTek filtration

BACKGROUND

The company is positioned as a leader in the separations industry with proprietary filtration technologies. SpinTek has developed significant enabling technologies that address the critical separations needs of its target markets and obtains proprietary access by invention, license or alliance.

The company provides full-service solutions by undertaking problem evaluation, solution design, installation, maintenance, monitoring and replacement of consumables. SpinTek uses these services and consumables sales to reinforce customer relationships within target markets.

The combined companies' competitive advantage is based on: an intimate understanding of a customer's separations needs; a portfolio of proprietary enabling technologies to provide the customer superior economics; and overlaying services and consumable product support.

Critical skills that will lead to a successful realization of this partnership includes: applications engineering expertise in the target markets; technology invention/acquisition & management skills; project management/execution skills; and systems design/assembly skills.

The SpinTek proposed AHCV effluent treatment process consists of three (3) unique technologies integrated into one process for the removal of solids. The process will filter the solids from the AHCV effluent directly without pretreatment and also after electro-coagulation and/or flocculant treatment.

The filtration process consists of:

1) Alloy Filter
2) Crossflow/Alternating Flow Configuration
3) Rotary filter configuration

SpinTek filtration

Alloy Filters

SpinTek's alloy filter consists of a thin elastic titanium dioxide/alumina/silica dioxide coating on a stainless steel or titanium substrate. The ceramic coating is 15 microns thick while the lower metal substrate is 250 microns thick. The pore size of the ceramic coating can be varied from 0.07 to 0.5 microns.

Figure 1 is a scanning electron microscope (SEM) view of a 0.2-micron pore size filter showing the 3-micron stainless steel particles coated by the nanopowder ceramic layer.

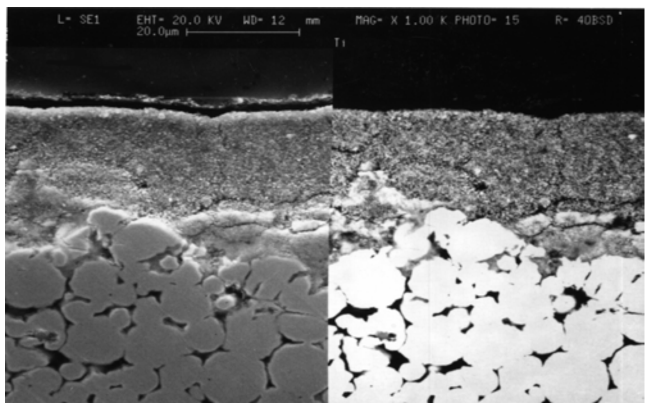


Figure 1: SEM Micrograph of a 0.2-micron pore size filter (250X)

(The large spheres are the substrate 316 and the fine coating is ceramic)

The filter is ductile enough to be rolled into a ½" (12mm) tube without cracking either the metal support or the ceramic coating. The filter can also withstand denting because the nanopowder coating is elastic to resist fracture. Figure 2 shows the ductility and mechanical strength of the alloy filter.

Figure 2: Alloy Filter rolled around a pencil and struck with a hammer

SpinTek filtration

Stack Alloy Filter

SpinTek has developed a cross flow filter utilizing the alloy filter in addition to its well documented service in the SpinTek rotary filter. The base component of the system is the alloy filter. Two (2) sheets are placed back to back (ceramic coating facing outward) with a filtrate carrier of stainless woven mesh system in the center. The edges of the two alloy filters are welded for a sure and reliable seal to form a filter plate. The center of the filter device is punched with a ½" diameter hole through which the filtrate can pass from filter plate to filter plate and then exit the module.

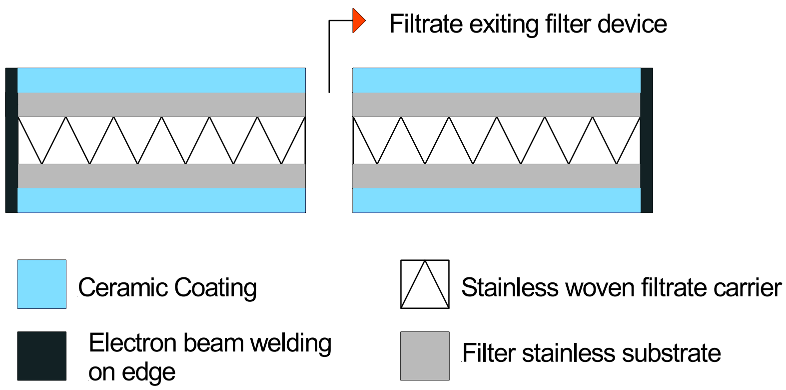


Figure 3: Alloy Filter plate

Typically these filters are stacked in heights of 24. There is a rubber grommet placed between each filter plate to seal the filtrate from the feed.

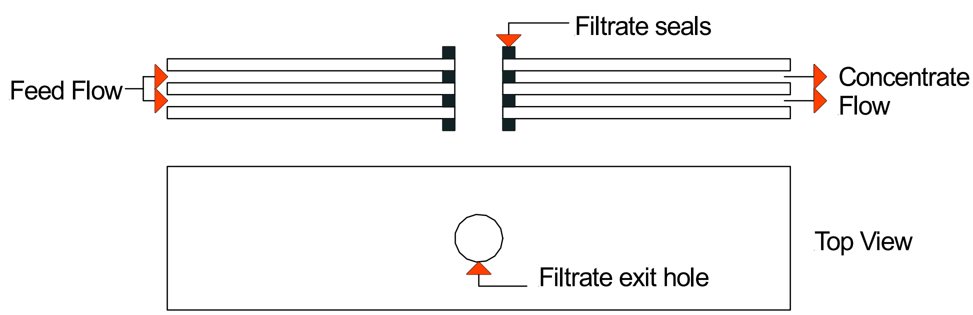


Figure 4: Alloy Filter device showing Side and Top View

SpinTek filtration

The following shows the flow path of a cross flow filter with three (3) filter plates. The orange (dark) arrows indicate the feed flow path between the filter stack and exiting out as concentrate waste water. The blue (light) arrows indicate the path of the clean filtrate for disposal.

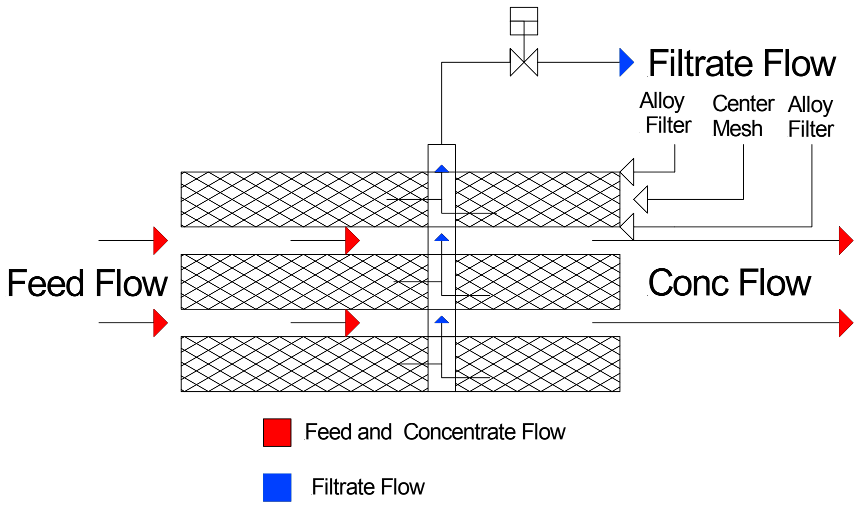


Figure 5: Flow Diagram of Stack Filters

A significant advantage of this system is that the alloy filter can be incorporated into a simple and compact system. Sixty-seven (67) square feet of filter can be configured in six inch flanged housing with ¼" spacing between filters which translates to a packing density of 33.5 ft2/1 cubic foot of volume.

To form the module there are four stacks of filter plates with each stack containing 24 plates.

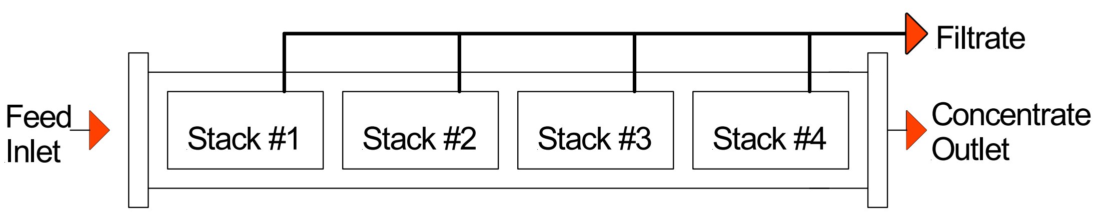


Figure 6: Alloy Filter device showing Module Stack Arrangement

It is also possible to monitor the effluent quality from each of the four (4) stacks. If one stack is leaking, that stack can be shut off while the remaining three (3) stacks remain in service.

When the module requires servicing, all of the filter plates can be easily removed from the module. A damaged plate or a series of plates can changed without having to scrap the entire module. A module can be disassembled and reassembled in 1 hour.

A unique feature of the filter module is that the filter plates can be cleaned by reversing the feed and concentrate flow to flush solids away from the surface of the filter and also by back flush cleaning.

SpinTek filtration

Figure 7 shows the laboratory crossflow test module that would be used in Phase II of this program. The blue plates are the two-sided filter sheets that are welded along the edges. This design allows the feed channels spacing between filter plates to be varied.

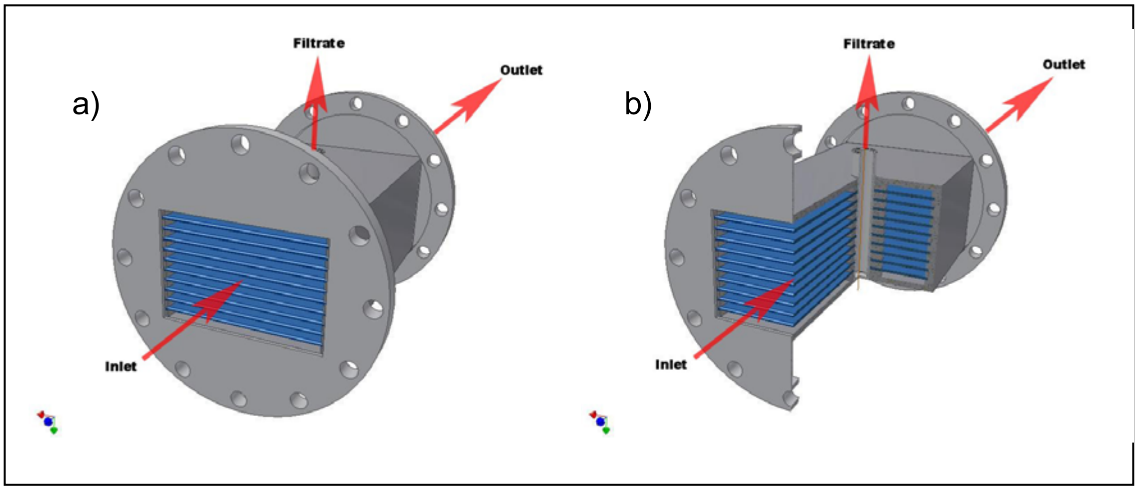


Figure 7: a) Alloy Filter Housing b) Cutaway Module

The module is shown in these drawings with standard ANSI 150# flanges but we propose using quick disconnect type of fittings for ease of maintenance.

The complete size for a module containing four (4) stacks of 24 plates is:

Length:	52 inches
Height:	6 inches
Depth:	6 inches

Advanced Rotary Disk System, SPEEDY

The rotary disk system is a high shear device that produces a crossflow velocity of > 60 feet per second.

The rotating disk system is a rugged and compact filtration system. Filter material mounted on rotating disks produce higher filtration flow rates, with stable performance, even when operating on heavily contaminated feed sources. The filters rotate at a tip speed velocity of 60 feet per second effectively sweeping solids off the filter surface maintaining stable filtrate throughput.

SpinTek filtration

The system is comprised of one or multiple rotating disks covered first with an woven filtrate carrier and then with alloy filters, physically mounted and hydraulically connected to a common hollow rotating shaft. The column of filter disks is enclosed within a pressure vessel. The feed enters one end of the pressure vessel, flows between the disks, where permeate flows through the alloy filter into the hollow disk and exits through the common hollow shaft. Concentrate exits the pressure vessel at the opposite end.

The disks are shown connected to a hollow shaft which turns the filter disks and acts as a conduit for filtrate exiting the system.

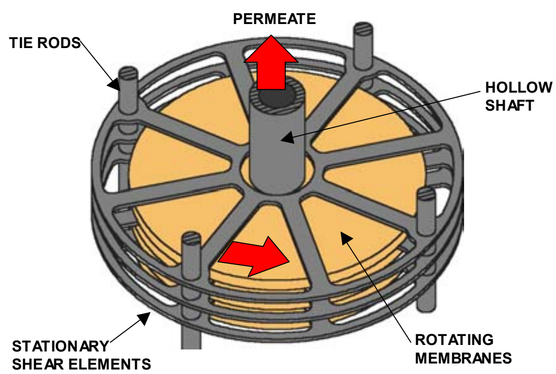


Figure 8: Schematic Representation of the disk

The incorporation of stationary surfaces shown in gray are turbulent promoters that oppose the rotating filter disks generating large fluid shear rates across the filter surface. This effectively eliminates the boundary layer that forms in conventional systems yielding very high fluid flux rates through the filters.

The Speedy system design shown in Figure 9 is unique in that it incorporates a hollow motor shaft though which the filtrate flows. The internal shaft design minimizes the system footprint, improves mechanical reliability, and reduces maintenance costs.

Figure 9: The Speedy System

SpinTek filtration

The Speedy system configured with an 11 inch diameter alloy filter disk weighing less than 1.5 pound was tested in Phase I for its ability to concentrate the raw feed. Each filter disk contains one (1) square foot of active filter service.

The rotary filter incorporating the alloy filter is capable of concentrating organic and inorganic solids to a very thick paste without fouling. The system is able to reach these high concentrations without prefiltration, coagulating chemicals or filter aids while operating for long periods of time between cleaning.

PHASE I : Small-Scale Test

The objectives of phase I were:

- Test the SpinTek alloy filter (metal and ceramic) on the Static-Test-Cell (STC).
- Process the raw solution on the Speedy rotary filter with an alloy filter to determine the effectiveness of high shear on filtrate throughput.

The SpinTek alloy filter proposed for this solicitation is constructed of a stainless steel substrate with a nanopowder ceramic coating. The nominal pore size is 0.2 microns.

The filtrate was always clear during testing in Phase I and even with a starting concentration of 4% total suspended solids (TSS) the STC was producing 9 mls/minute or 68 gfd (gallons per square foot per day).

Experimental Procedure

Two different tests were performed on the AHCV effluent. The first one used the STC system to qualitatively and quantitatively analyze the alloy filters performance in a cross flow manner. After the STC test another series of tests demonstrated the qualitative and quantitative quality of filtrate on the Speedy system.

For both systems the test filter was run in a 100% recycle mode and then in a concentration mode. A general flow diagram of the test is shown below in Figure 10.

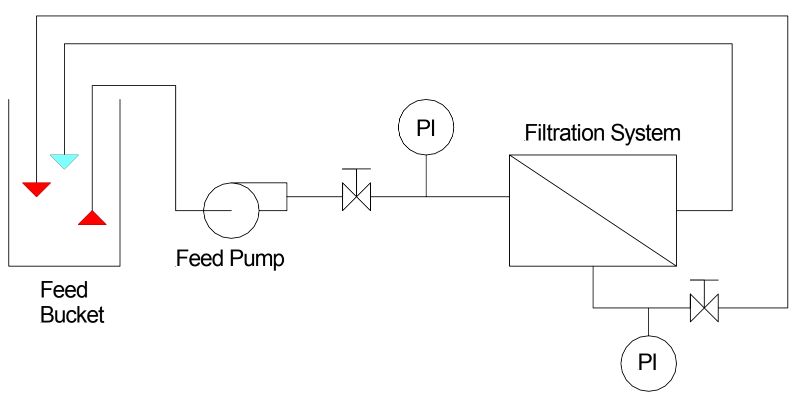


Figure 10: Filtration System in 100% Recycle Mode

SpinTek filtration

The filtration test system used a feed bucket, electric diaphragm pump and a 0.2 micron alloy filter.

Once the system stabilized performance, the filtrate line was removed from the feed tank as shown in Figure 11 allowing concentration of the feed solids.

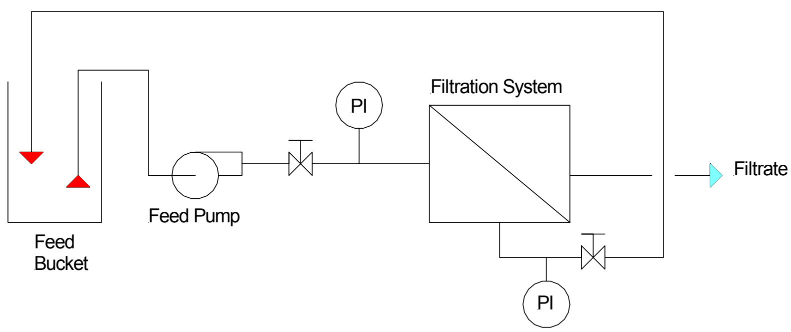


Figure 11: Filtration System in Concentration Mode

At regular time intervals, we measured the following parameters in the concentration mode of both tests:

- Outlet Pressure
- Filtrate Flow
- Feed Temperature

In addition a feed sample was dried and weighed to measure total solids (TS) in the feed solution. A filtrate sample was also dried and weighed; based upon the use of a 0.2 micron filter, it was assumed that all solids in the filtrate were soluble or dissolved solids (TDS).

The starting Total Suspended Solids (TSS) was calculated as follows:

TS of feed – TDS of filtrate = TSS of feed

SpinTek filtration

Results and Analysis

1) STC

After running the system in the recycle mode for 2 hours, we switched to the concentration mode, keeping the temperature and the pressure constant at 70 F and 30 psi.

Figure 12 shows samples of the AHVC effluent and the filtrate from the STC. The clarity of the filtrate was consistent throughout the filtration process in the concentration mode. The alloy filter is a good candidate for the filtration of the AHCV wastewater since the separation gives a clear filtrate with a green tint as shown in the figure below.

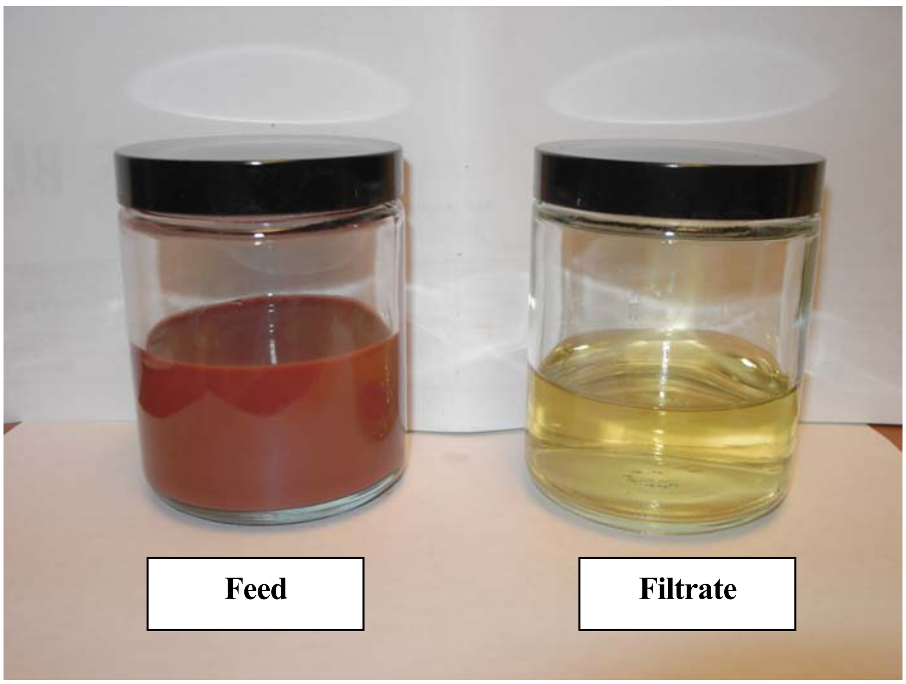
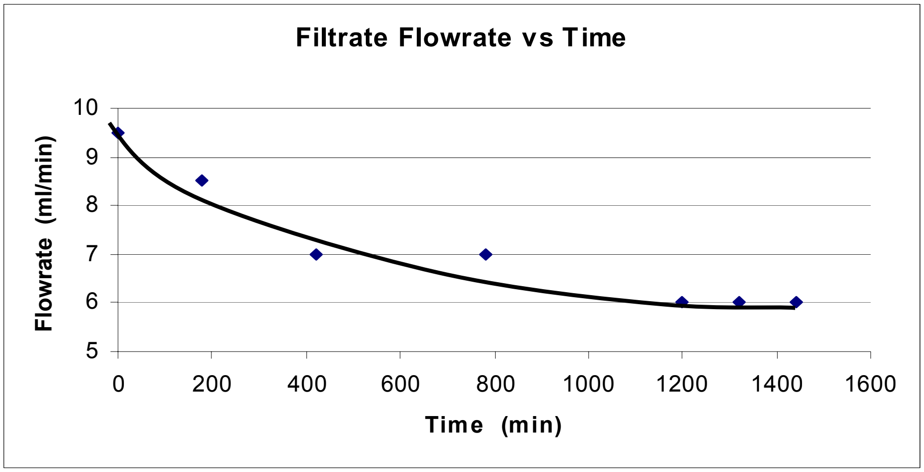


Figure 12: Picture of samples of feed and filtrate

Filtration flow rate measurements were taken and plotted in Graph 1. The flow rate slowly decreased as the feed was concentrating. The flowrate started at 9.5 ml/min and reached after 20 hours a stable value of 6 ml/min. The average flowrate was 7 ml/min and the related flux was 53 gfd (gallons/square foot of filter over 24 hours).

Samples of the starting AHCV wastewater and the initial filtrate from the STC were measured for solids content. After drying a known amount of feed the initial AHVC feed (TS) was measured at 6%. Filtrate after weighing and drying showed (TDS) at 2% hence the (TSS) of the AHVC feed was 4%.

SpinTek*filtration*



Graph 1: Filtrate Flowrate vs. Time with the STC

The change in the physical properties was the main reason for this flowrate trend. Indeed, as the feed was concentrating, it became thicker and more viscous. Hence, the boundary layer grew and a cake formed at the surface of the alloy filter. This was expected from the STC. The Graph 1 demonstrates that the alloy filter in a cross-flow configuration such as the SpinTek stacked plate design is suitable for the initial concentration of the raw feed.

After 24 hours of filtration in the concentration mode, the feed was concentrated 2.7 times. Thus, we were able to obtain a total amount of suspended solid (TSS) in the concentrated feed of 9.4%.

A very significant factor that needs to be taken into account is the difference between the expected feed solution from the pier side versus the sample that SpinTek was provided to test with.

Previously it was shown that the TS – TDS = TSS and that the total TSS of the SpinTek sample was 4% or 40,000 mg/l of suspended solids.

The anticipated feed TSS level is only 800 mg/l or .08% of the feed solution on fresh waste water.

This demonstrates that even when the STC, and later the Speedy system, was tested each system was already receiving AHVC feed that is a 50 X (98%) concentration of solids over what is anticipated at pier side.

In Graph 1 the flow rate for 0.05 ft^2 of filter in the STC was 9 milliliters per minute at a 98% concentration of solids.

A filter plate has 1.0 ft^2 of filter thus the flow rate would be equal to 9 milliliters/.05 ft2 = 0.048 gpm/plate.

SpinTek filtration

A single module contains 48 plates thus the flow rate per module is 48 x 0.048 gpm/plate = 2.3 gpm/module.

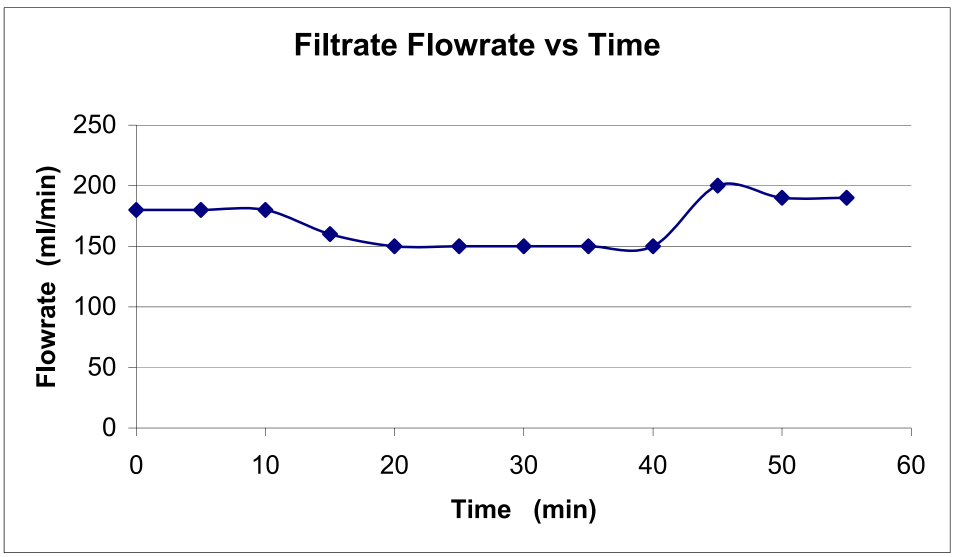
The entire flow rate at a rate of 50 gpm requires 50 gpm total/2.3 gpm/module = 21 modules.

If the feed flow was reduced to 10 gpm the 10 gpm total/2.3 gpm/module = 4.2 modules.

Consequently, if the 6 mls/minute performance of the STC at a feed concentration of 9.6% TS is used as a baseline performance, then the 50 gpm system would require 32 modules and the 10 gpm system 6 modules.

2) Speedy

After running the Speedy system in the recycle mode for 24 hours, we switched it to the concentration mode, keeping the temperature and the pressure constant at 92 F and 27 psi. The filtrate flowrate was collected at five-minute intervals until the feed reached a low level (~ 1 liter). The results are compiled in the Graph 2.



Graph 2: Filtrate Flowrate vs Time with the Speedy

SpinTek filtration

Unlike the STC, the Speedy gave a fairly steady filtrate flow rate varying from 150 ml/min to 200 ml/min. It took 55 minutes to produce 3.355 gallons of filtrate from the AHVC raw feed.

The rotating filter disk - turbulent promoter- generates large fluid shear rates across the filter surface. This effectively eliminates the boundary layer that forms in conventional systems yielding very high and constant fluid flux rates through the filters.

Figure 13: Flow Path of Rotary Filter

Using the same initial feed with a TS of 6% we found the filtrate collected from the speedy had the same amount of dissolved solid (TDS) of 2% as the filtrate from the STC. Therefore, the total amount of suspended solid in the initial feed (TSS) is 4%.

The concentration factor in this filtration process was 5.4 X. We were able to concentrate the 4% feed to a total amount of suspended solid (TSS) of 21.6%

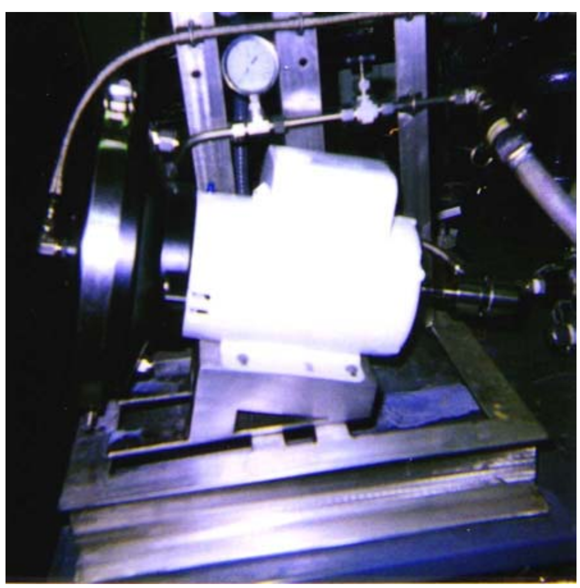


Figure 14: Speedy in Operation on AHVC Sludge

SpinTek filtration

Conclusion

Based upon the data shown we are confident that a two-stage process of a cross flow and a rotary filter in series can provide the basis of a "push button" processing plant. The feed will enter the filter stack and the concentrate from this stack will be sent to the rotary filter for final concentration. The combined filtrate from both filter systems will be combined and sent directly to the POTW under pressure. The concentrate from the Speedy is also pressurized and the waste can be directed to storage tanks or barrels for final disposal.

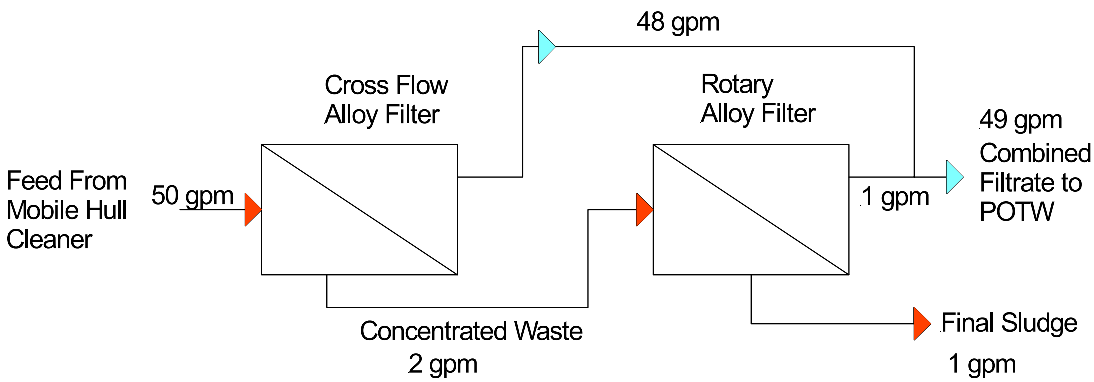


Figure 15: Flow Sheet of Filter Stacks and Rotary Filter

Note that the flow rates listed above are approximate and will vary depending on the results of the next phase of testing. Not shown are flow control valves that will maintain a constant flow rate to the rotary filter with varying feed/concentrate flow from the filter stacks.

Figure 14 is an initial layout of the thirty (30) cross flow modules and the 25 disk rotary Speedy system.

SpinTek filtration

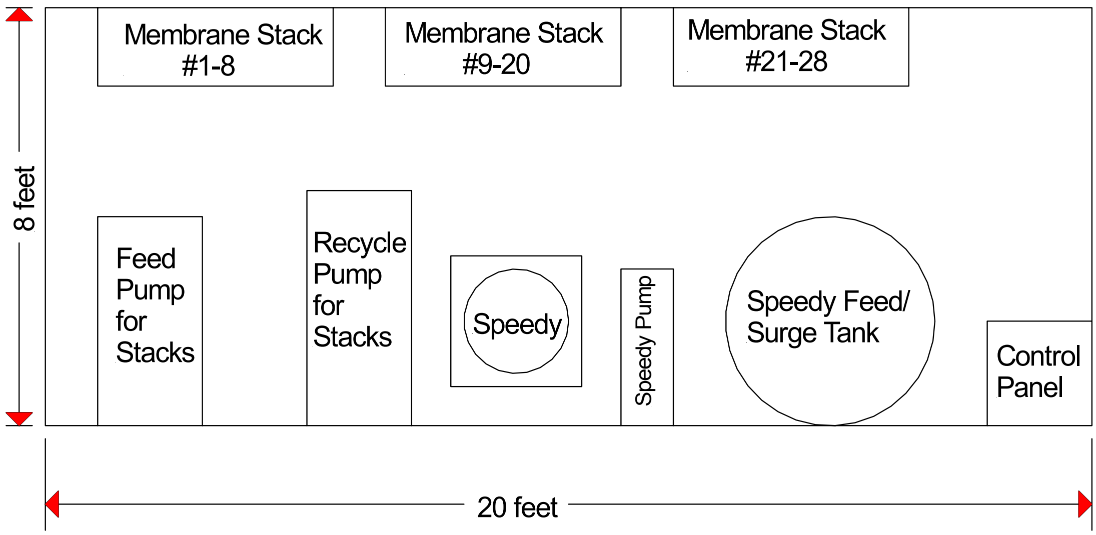


Figure 16: Preliminary Layout of Filter Stacks and Rotary Filter

The layout is very general in nature to show the major pieces of equipment required for a 50 gpm system. Note that the space of 8 feet x 20 feet to handle twenty-four (24) cross flow modules, pumps, Speedy feed tank, and a full size Speedy system. The 20' trailer is also large enough to fit another Speedy system and an additional twelve 912) cross flow filters.

These results need to be taken in light of the expected suspended solids in the AHVC wastewater to be 800 mg/l (TSS) while in our test the feed was 40,000 mg/l (TSS). We would expect that the filter stack and the rotary filter will provide even higher throughput per area of filter then shown in Phase I of this test.

It should be noted that all separations and tests performed were without the use of any flocculants or chemical additions to the feed.

SpinTek filtration

PHASE II: Overview and Technical/Commercial Objectives

Technical Objective

The purpose of the Phase II work plan is to develop data that will allow for the design of a pier side system capable of treating at a minimum 10 gpm of filtrate up to a maximum of the full scale requirement of 50 gpm.

The work on the STC system demonstrated that with moderate concentrations of solids (4% - 9.4% TSS or less) in the feed stream an alloy filter in cross flow configuration is suitable as a preconcentrator. Phase II will determine what the long term flux versus solids concentration graph is.

A major task to Phase II will be the relative difference in performance between the cross flow and the rotary systems illustrated below.

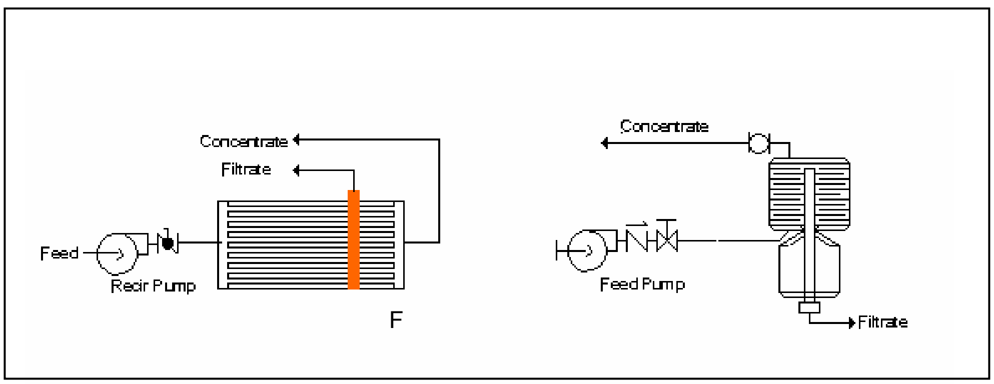


Figure 17: Filter Stack and Rotary Flow Schematic

The same flux versus solids curve will be developed for the rotary filter demonstrating sustainable fluxes at various solids loading.

The two flux curves will be integrated with other factors such as capital and operating expense of the alloy cross flow filter and the rotary filter to determine the most cost effective and reliable configuration.

The specific purpose of Phase II is to demonstrate and develop data per the following requirements.

Filter Stacks
- Determine if STC results can be duplicated on a larger alloy cross flow filter with a minimum of 4 filter plates.
- Use much larger feed samples (100 gallons+) so the system can concentrate to the maximum extent possible and not be limited due to hold up volume requirements.
- Determine the flux stability of the stack and its ability to concentrate to target levels.
- Generate analytical data TSS in the feed stream and in the final concentrate.
- Provide detailed data for the construction of a full scale module that is suitable for pier side demonstration.
- Generate a concentrated solution that is suitable as feed to the rotary filter.

Rotary Filter
- Operate the rotary filter on concentrate from the filter stacks and confirm the test data generated in Phase I of this program.
- Determine the flux stability of the rotary filter and its ability to concentrate to target levels.
- Generate analytical data as to the TSS in the feed stream and that in the final concentrate.
- Provide detail data for the construction of a larger full-scale module that is suitable for pier side demonstration.

Conclusion

We believe that the alloy filter has been successfully tested in Phase I and provides a basis for work to proceed in Phase II.

Based on the preliminary test results, the entire two stage process could be fit into a standard 20’ long trailer.

The overall goal of Phase II is to provide a capital/operating cost per gallon of filtrate at various solids concentrations. This will allow the Navy to determine deployment cost of the full scale technology.

The cost to process the raw feed to various solids concentration levels can be compared to other treatment processes and/or waste hauling charges.