Testing Dual Rotary Filters - 12373

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ABSTRACT

The Savannah River National Laboratory (SRNL) installed and tested two hydraulically connected SpinTek® Rotary Micro-filter units to determine the behavior of a multiple filter system and develop a multi-filter automated control scheme. Developing and testing the control of multiple filters was the next step in the development of the rotary filter for deployment. The test stand was assembled using as much of the hardware planned for use in the field including instrumentation and valving. The control scheme developed will serve as the basis for the scheme used in deployment. The multi filter setup was controlled via an Emerson DeltaV control system running version 10.3 software. Emerson model MD controllers were installed to run the control algorithms developed during this test. Savannah River Remediation (SRR) Process Control Engineering personnel developed the software used to operate the process test model. While a variety of control schemes were tested, two primary algorithms provided extremely stable control as well as significant resistance to process upsets that could lead to equipment interlock conditions. The control system was tuned to provide satisfactory response to changing conditions during the operation of the multi-filter system. Stability was maintained through the startup and shutdown of one of the filter units while the second was still in operation. The equipment selected for deployment, including the concentrate discharge control valve, the pressure transmitters, and flow meters, performed well. Automation of the valve control integrated well with the control scheme and when used in concert with the other control variables, allowed automated control of the dual rotary filter system. Experience acquired on a multi-filter system behavior and with the system layout during this test helped to identify areas where the current deployment rotary filter installation design could be improved. Completion of this testing provides the necessary information on the control and system behavior that will be used in deployment on actual waste.

INTRODUCTION

The SpinTek Filtration® high shear rotary filters used in this testing have 25 filter disks per unit with each side covered with 0.5 micron pore size (nominal) sheet membranes manufactured by Pall Corporation (PMM050). The filter area of each disk is 0.09 m^2. The disks are physically mounted on and are hydraulically connected to a common hollow rotating shaft. The entire stack of membrane disks is enclosed within a vessel. Feed is fed into the filter vessel through the inlet on the side of the vessel wall. A pressure is set in the tank by restricting the outlet flow by use of a valve on the concentrate piping. This applied pressure forces liquid through the filter membranes on the filter disks. Between each disk is a set of baffles (turbulence promoters). These turbulence promoters cause strong currents and eddies at the surface of the membranes inhibiting the formation of filter cake on the disks. Filtrate flows through the media and along a mesh inside the disk into the hollow shaft. The filtrate then flows through the shaft to a rotary joint which allows the spinning shaft to couple to stationary piping. The concentrated slurry exits the vessel through an outlet on the bottom of the filter tank. The rotary filter technology has been discussed at length previously and additional detail on the internals of the rotary filter can be found in References 1, 2, 3, 4, 5 and 6.

The SpinTek rotary microfilter has been developed by SpinTek Filtration® and SRNL under the Department of Energy (DOE) Office of Environmental Management (EM) for the purpose of deployment into radioactive service in the DOE complex [1], [2], [3], [4], [5], [6]. In order to advance the readiness of the technology for deployment, SRNL was requested to install and test multiple full scale filter units to determine the hydraulic behavior and to allow SRR to develop control logic for operation of the filters during deployment with the Small Column Ion Exchange (SCIX) system. The control system tested in these experiments will be the platform for deployment with actual waste.

METHOD

SRNL installed two rotary microfilter units hydraulically connected in a parallel flow configuration. A series of operational tasks were performed with the dual filter setup. A primary objective of this task was to develop the logic of the control system for operating multiple filters in the field. SRR personnel provided the single-loop, digital control system for testing and developed the operational algorithms. Two primary tests were completed. The first was to determine how to start multiple filters essentially simultaneously; the second, to determine how to start a second filter after the first filter had been at a quasi-steady state operation.

The first test challenged the control system to rapidly adapt to the numerous dynamic changes occurring during startup. The control system must maintain operational parameters (minimum pressure) required by the vendor during these changes. The second test also challenged the rapid response of the control system due to changes in flow and pressure dynamics. The difficulty in this case was that the second filter to be brought online was significantly “cleaner” than the filter that had been running at a quasi-steady state. The cleaner filter provided a significant flow path that had to be accommodated by the control system. The shutdown of one of the filters after both had been operating had similar logic control issues, where the control system must adjust demand with the loss of one of the filters. Rapid changes to system parameters by the control system can result in loss of operational integrity.

The rotary filters were run with water for a period of time as necessary to evaluate instrumentation, calibrations, test for active component control (i.e. start, stop, interlocks, alarms, etc.), and collect some experience with the system behavior and interactions. Later simulant feed was introduced into the feed tank. The feed was composed of a simulated salt solution and a simulated sludge. The process model was operated for two 100 hour periods using the control logic developed for deployment. Although continuous operation was not expected, extended (i.e., overnight and weekend) operation was intended. Therefore, the operating system had to accommodate unattended operation. Interlocks and alarms were programmed into the control system to provide equipment safety during unmanned operations using instrumentation. The interlocks would shut down the filters and the feed pump when certain parameters exceeded critical values.

Installation

Two rotary filters were installed in a hydraulically parallel configuration using as much of the equipment and instrumentation as possible that is intended for SRS Tank 41H deployment for the small column ion exchange process. To simulate the hydraulic aspects of the tank-top configuration, the filters were placed on a second-level mezzanine with the feed tank on the first level. This configuration provided a layout similar to the layout proposed for the actual waste tank. Installing the filters using the layout proposed for deployment proved to be an important operating consideration.

An original intent of the installation was to verify the proposed tank-top support configuration of the filters and filter motors. The bank of filters and their respective motors were to be independently supported since they were isolated by the required shielding between them. This original mounting configuration proved to be insufficient due to excessive vibration. Additional support structures were required to stiffen the structure for continued operation at tolerable vibration levels. A photo of the final reinforced filter setup is shown in **Error! Reference source not found.**.

Figure 1. Dual Filter System Installed at SRNL

Equipment

Due to the limited space in the deployment design, minimal instrumentation was designed into the system. The configuration required measurement only of the combined filtrate flow rate, the feed pressure in the combined line prior to the filters, and the filtrate pressure after the lines converged (the feed pressure and filtrate pressure would provide differential pressure across the filter bank). Additional equipment and instrumentation were included in the final SRNL test configuration to provide information regarding the operation of individual filters and to facilitate secondary activities such as cleaning and sampling. Additional flow and pressure measurements were incorporated to provide operational data for each filter. Flow was measured by magnetic flow meters in the separate concentrate lines and the separate filtrate lines. The differential pressure was measured across each filter.

Error! Reference source not found. highlights the additional instrumentation added by SRNL in red. Additional flow meters were added to each filtrate and concentrate line to determine the individual flow rates. Pressure drop measurement was also added across each filter from feed to filtrate. The additional instrumentation was not intended to provide input to the control system for filter operation.

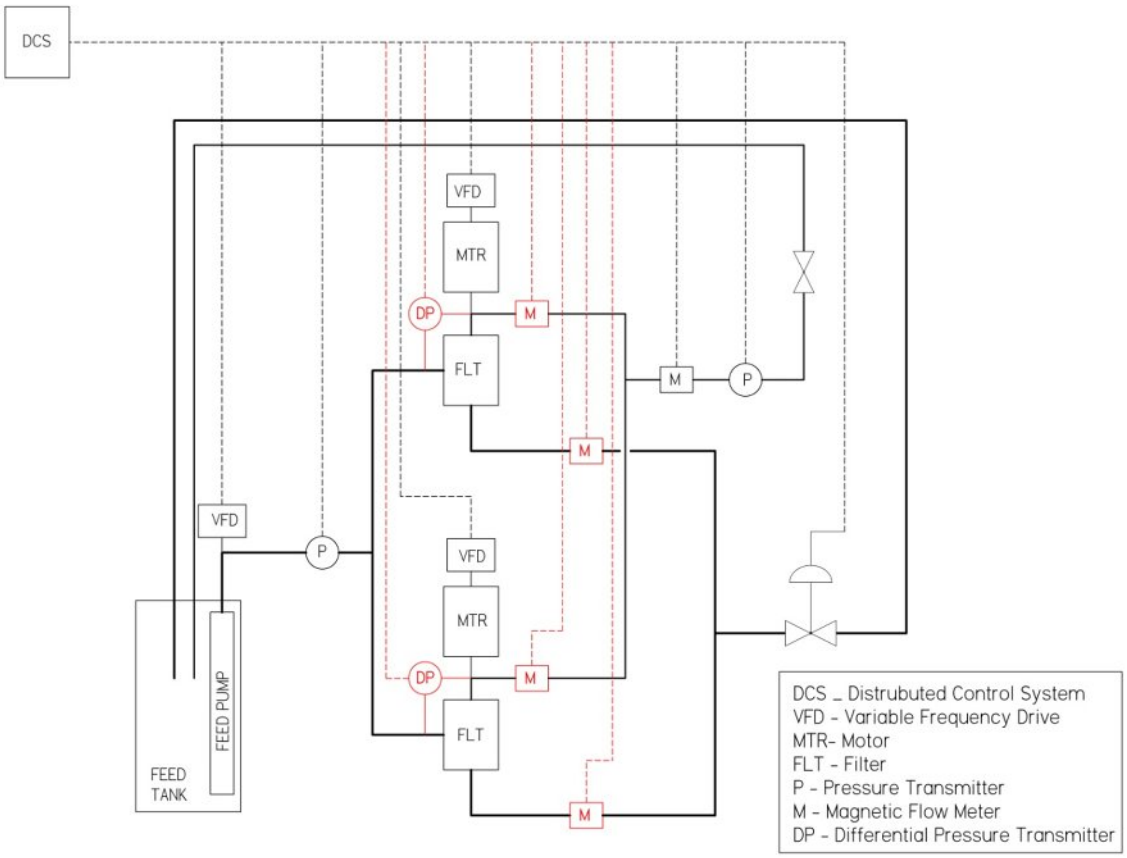

Figure 2. Process Instrumentation Diagram Showing Additional SRNL Instrumentation

The test piping was a closed loop system**Error! Reference source not found.**. The concentrate and filtrate returned to the feed tank to allow continuous operation with a small feed volume. As shown in the process diagram, filter feed is provided by a submersible pump in the 180-gallon feed tank. The flow rate of the feed pump and the feed tank size provided rapid turnover of the tank and assured adequate mixing. The feed line split into two separate lines prior to entering the inlets on the side of each filter. The individual feed lines were similar in construction to provide an equal hydraulic resistance in the lines. Concentrate discharged from the bottom of the filter housing. The concentrate lines converged prior to entering the feed tank and were similar in construction to provide equal hydraulic resistance. The combined concentrate line contained the air-driven control valve to provide back pressure to the filters and a tube in shell heat exchanger to provide temperature control. Filtrate discharged from the rotary union of each filter. The filtrate lines converged prior to entering the feed tank and were similar in construction to provide equal resistance. A manual gate valve in the filtrate line downstream of the total flow meter provided back pressure in the filtrate line. This backpressure simulated downstream pressure drops, such as ion exchange columns, that would be found in deployment configuration.

Each filter was powered by a 20-hp, alternating current electric motor with a maximum rotation speed of 1175 revolutions per minute (RPM). Rotational speed for each was controlled by an Allen-Bradley variable frequency drive (VFD). Feed to the filters was provided by a Grundfos model 150S150-6 submersible pump in a 180-gallon supply tank. The motor speed of the pump was controlled by an Allen-Bradley VFD.

The control valve on the concentrate piping was a 5.08 cm air actuated globe valve from Fisher Controls model NPS 2 EZ 667 size 45 with a DVC6010 communication module.

Temperature was measured in several locations to obtain operational data and maintain safe operation. Feed temperature was measured in the feed tank. Room temperature was measured in the vicinity of the test equipment. The metal surface temperature at the feed pump outlet was monitored to prevent exceeding the pressure limitation of the chlorinated polyvinyl chloride (CPVC) pipe de-rated by heat from the pump. Likewise, the concentrate temperature was measured at the outlet of the filters. The metal surface temperature of the main bearing housing for each filter was monitored to indicate bearing problems.

The feed tank had several level detection devices to assure safe operation. Two low-level switches (low and low-low) indicated loss of feed. A high level switch indicated an unintended addition of a fluid to the feed tank (i.e., fluid from one of the cooling systems). And finally, a level detector was employed to provide tank level measurement and to verify switch enunciation.

The piping system was constructed using CPVC pipe of varying sizes (1.27 cm to 7.62 cm) to emulate the system deployment design. Quarter-turn isolation valves were added to the piping system to accommodate cleaning, sampling and various other activities.

Simulant

The slurry simulant is a Savannah River Site Sludge Batch 6 simulant, but did not include Resource Recovery and Conservation Act (RCRA) metals or halides. Optima Chemical was contracted to fabricate the simulant. This simulant has been used in previous tests [5], [6]. Soluble salts were added to the simulated sludge to produce a simulated supernate of 5.6 molar sodium. The bulk supernate composition was a representative SRS salt solution and predominately sodium hydroxide with nitrate and nitrite. The insoluble solids also included monosodium titanate (MST) and the material used in the testing was the same material (Harrell Industries Lot #102209) currently used in the Actinide Removal Process at SRS. Filter performance has been tested with actual waste [1] as well as multiple simulants [2], [3], [4], [5], [6] in the past and therefore was not a primary objective of this test. This simulant used in this testing was selected due to availability and has shown to be representative of SRS waste [5], [6].

Control System

The control system for the dual filter test used a personal computer based DeltaV architecture supplied and programmed by SRR personnel. The control system communication with equipment and instrumentation was through either conventional discrete digital and analog or fieldbus input/output (I/O) interface. The VFD interface was via DeviceNet protocol. The control valve, two pressure transmitters, and thermocouples communicated via Foundation Fieldbus protocol. The remaining components' interface was through conventional discrete digital and analog 4-20 milliamp loops.

The purpose of the control system was to maintain a specific filtrate flow rate over a range of operating conditions with the valve position and the feed pump speed as control variables. The filtrate flow and concentrate flow loops are highly coupled. A variety of control schemes were tested to identify methods of decoupling and limiting the interaction between the two control elements. Target filtrate flow was anticipated to be approximately 15 liters per minute for the two filters. However, filtration rate was not the primary objective of this testing, and several target flows were used during testing to probe variations in system response.

RESULTS

In the planned deployment, the filters will be operated with a fixed output. Therefore, the filtration rate was fixed and the other system parameters, primarily system pressure and the resulting pressure drop across the filter membranes, were altered to meet the filtration rate goal**Error! Reference source not found.**.

The pressure drop required to achieve the filtration rate set point for both tests was greater than expected. During Test 1 Filter #1 showed evidence of blocked filter media. This was evident due to the reduced production as compared to the historic water flux performance [5], [6] as well as a large discrepancy between filtration rates of Filter #1 and Filter #2 (Filter #2 flux was almost four times that of Filter #1). The difference in performance between the two filters provided an additional challenge to the control system. Filter #1 was cleaned between tests and performed closer to Filter #2 in Test 2.

During the small column ion exchange process, the rotary filters will be providing feed to the ion exchange columns. The ion exchange columns operate most efficiently with a constant feed rate. The control system for the rotary filters has been designed to adjust filter parameters to provide a constant filtrate rate. The goal of the control system was to be able to adjust to gradual changes in filter conditions, such as fouling of the disks, as well as dynamic changes such as filter startup or shutdown.

During both tests, the filters were primarily run at a reduced rotational speed. Historically, the filters have been operated at approximately 1200 rpm. Two issues required the reduction of the filter speed during the tests. During Test 1, the vibration amplitude was very significant at full speed, due to approaching a resonant frequency in the support structure. Operating at reduced speed for the filters while the test stand was being stiffened and motor-to-filter alignment improved kept the vibration to a manageable level. Secondly, operating the filters at full speed added to the heat load of the system and exceeded the system cooling capacity of the facility. The filters had to be run at reduced speed to maintain the temperature of the process fluid. It is anticipated that an increase in rotor speed would aid in the prevention of filter cake buildup and; therefore, maintain a higher filtration rate.

System Operation

The control system communicated with equipment and instrumentation through either digital or analog signals. The operator communicated to the control system through the PC based graphical user interface. The operator interacted with the system through this interface and input desired set points, primarily the filtrate production rate. The operating system was programmed in such a manner that adjusting two primary parameters, the concentrate flow control valve position and the feed pump speed, would dictate the driving pressure required to obtain the filtrate set point.

While the control logic was able to respond to gradual system changes, step changes initially caused problems. If a large change was made to a set point, the control logic altered the system variables to respond. The system would drive parameters such as pump speed or valve position until the set point condition was met or the parameter was driven to its maximum/minimum. For example, if an increase in filtrate demand was entered, the control logic would respond by altering the concentrate valve position. The valve position would continue to close until the new set point for filtrate demand was reached. If the system response was not fast enough, the valve would close entirely resulting in a loss of flow and consequential interlock of the system due to lack of concentrate flow. **Error! Reference source not found.** illustrates several of the monitored parameters and their responses as a set point is changed. A decrease in filtrate demand was entered. The system responded by opening the concentrate valve thereby decreasing pressure drop across the filters. The resulting decrease in filtrate flow overshot the new set point. The control system responded by closing the control valve. The corresponding increase in filtration rate was significantly slower than the valve response. The control system continued to close the control valve to increase the filtration rate until the valve closed completely, resulting in the shutdown of the system.

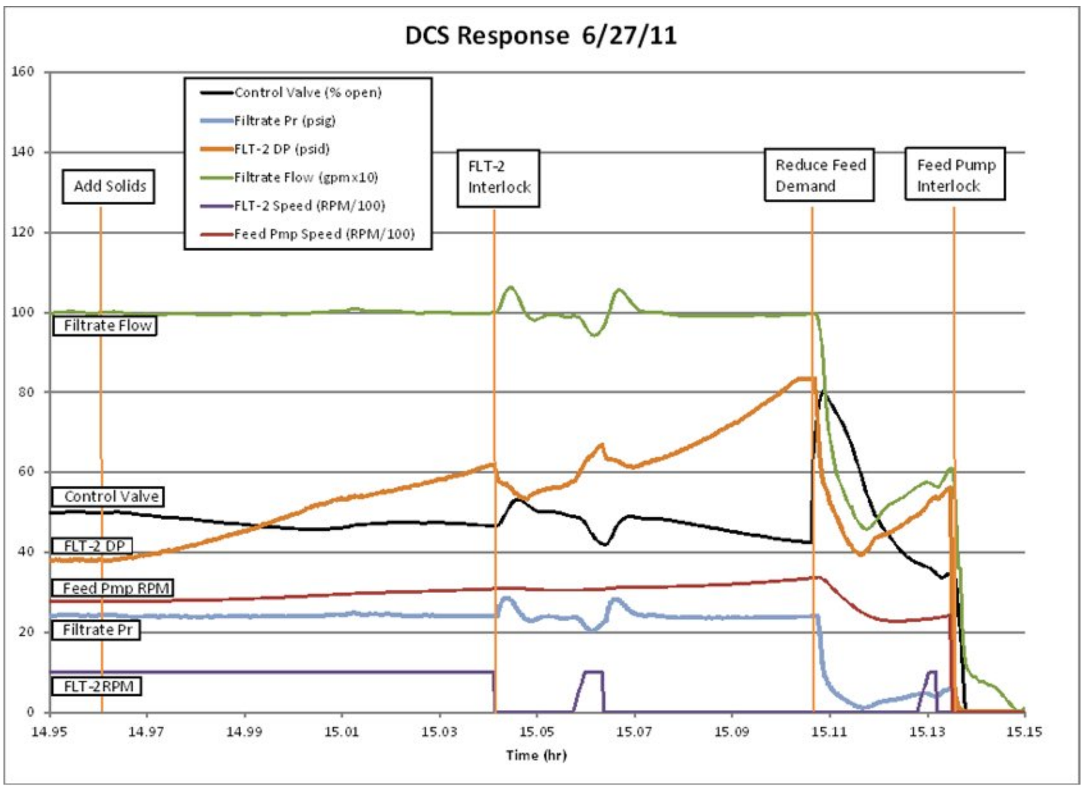

Figure 3. Control System Responses to Parameter Change Prior to Tuning

The control logic was tuned to respond to dramatic changes by altering several parameters without causing the system to shut down. This was accomplished by setting limits to the amount of adjustments that could be made to the response parameters. For example, the control valve position was limited to prevent a complete closure of the valve and resulting system shutdown. Other parameters were then altered, such as pump speed, to allow the system to achieve the new set point. An example of the tuned system response is illustrated in Figure 4. In this case, when a decrease in filtrate demand was input, the control system responded with by closing the valve in a less dramatic fashion and allowed the system to respond. The travel of the valve was limited and other variables, such as pump speed, were altered allowing the system to reach the new set point in a controlled manner.

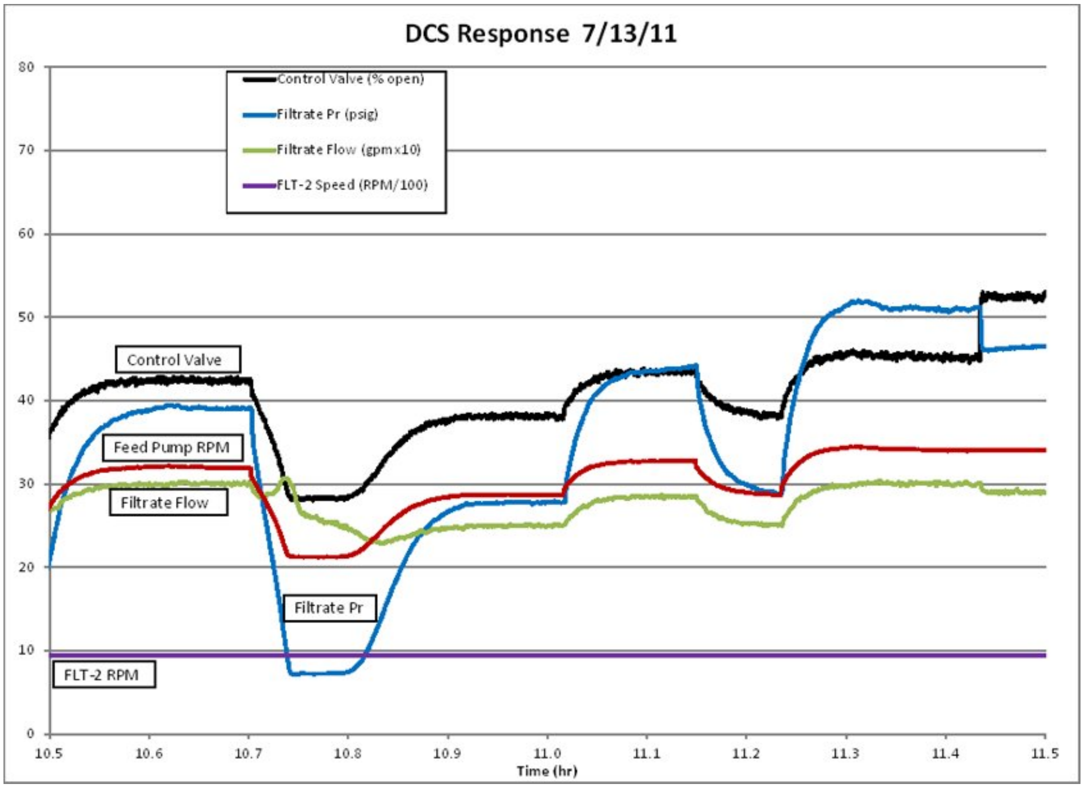

Figure 4 Control System Responses to Parameter Change after Tuning

Vibration

Casing vibration measurements were collected off the rotary microfilter units during dual rotary filter system testing. **Error! Reference source not found.**Sensors were arranged orthogonal at each elevation for recording information in two radial directions. A portable machinery analyzer (CSI model 2120-2) and general purpose accelerometers (Wilcoxin Research 742) were the primary tools used during monitoring. A speed series was conducted at the end of filter tests with a Data Signal Processing Instrument (ADRE 408 DSPi) and Velometers® (Bently Nevada 330500) to collect additional waveforms and generate spectra at different speeds.

Spectrum cascade plots for Filter #1 were obtained**Error! Reference source not found.** during startup and shutdown of the equipment. The full spectrum cascade plots showed a series of vertical peaks on different spectra. The fundamental, or first harmonic, appeared around 16.125 Hz (967.5 rpm). The frequency becomes visible in the plot around 600 rpm and the peak amplitude is fairly constant as the machine speed increases to 960 rpm. When the 1X forcing frequency, typically caused by a combination of runout, shaft bow and unbalance, reaches this frequency, the vibration amplitudes grow significantly and harmonics which track running speed are generated. These vibration frequencies are evident on the diagonal lines (1X, 2X, 3X) of the forward and reverse precession frequencies. The series of vertical peaks were witnessed to 960 revolutions per minute then disappeared, suggesting a sudden change in rotor system stiffness possibly by a rub, change in balance, or other form of resonance.

Sidebands are also evident in the cascades. These sum and difference frequencies are produced when one signal modulates another and can occur by nonlinearities and asymmetries in rotor systems or during rapid changes in machine accelerations or decelerations.

Error! Reference source not found. Filter #2 showed a vibration pattern similar to Filter #1 in data plots. This suggests the cause of the vibration is common in the design of the filter, or being caused by the equipment set up. Since previous testing with the same filter did not show the same vibration issues [5], it is believed that the vibrational issues were due to the equipment setup.

DISCUSSION

SRNL installed and tested two hydraulically connected rotary filter units. Both units were successfully controlled by a control scheme written in DELTA-V architecture by SRR Process Control Engineering personnel. The control system was tuned to provide satisfactory response to changing conditions during the operation of the multi-filter system. This was done by limiting parameter ranges to prevent unwanted results. The control system demonstrated stability through the startup and shutdown of one of the filter units. Filters were brought online through a manual startup and then turned over to the automated system for control.

The test installation, which was based on the configuration of independent filter and motor mounts proved to be troublesome for vibration. Significant stiffening of the filter and motor mounts was required to minimize the vibration. Isolating the vibration from the rotary union will significantly improve the lifetime of the seals.

The equipment selected for deployment, including the concentrate discharge control valve, the pressure transmitters, and flow meters, performed well. Automation of the valve control integrated well with the control scheme and when used in concert with the other control variables, allowed automated control of the dual rotary filter system.

Operational experience gained during development and testing suggests that some of the extra instruments available during testing are necessary and should be added to the final deployment production design. The test model provided individual concentrate flow meters. Both of the final control schemes developed for the multi-filter configuration rely on concentrate flow as a necessary process input. It is believed that a single total concentrate flow meter is adequate to provide the necessary feedback to the control system. Since filtrate flow is the primary process variable being controlled, the total filtrate flow meter is required. The control system does not need individual filtrate flow meters. The individual filtrate flow meters would however provide extremely valuable information to operations concerning the health and efficiency of the individual rotary filter units in the bank. Having individual filtrate flow reading would allow operations to run some or all filters based on filter performance. The flow rate through each filter can vary significantly. Without the individual filtrate flow instruments, it will not be possible for operations to recognize when a filter is plugged/plugging. As long as they can meet their minimum production flow rate, they would most likely run with one of more filters plugged without isolating the offending filter(s). This could lead to severe packing of the filter that might be severe enough to resist flushing in place. If the filter could be isolated, this situation might be avoided. Also, as the filtrate flow through a single filter approaches zero, the top seal and bearing may heat up and lead to premature failure. If it could be recognized, the rotor could be shutdown to prevent this type of failure.

Test experience indicates that extended deadheading of the filters leads to reduced filtrate from the filters [4], [5], [6]. It is believed that including mechanisms into the design that minimize this situation is important.

During the first 100-hour test using stimulant, the filter flux was lower than expected. The control scheme being used to run the process equipment was not mature. The transient caused when salt simulant and simulated sludge was added resulted in multiple interlocks of the filter rotors, and in some cases this led to feed pump interlock. Numerous restart attempts resulted in extended periods when feed pump pressure was applied to the rotary filter prior to filter rotation being established. It is believed that maintaining a sustained pressure drop across the filter disks prior to the start of the filter motor leads to a significant amount of solids being collected on the filter disks creating a buildup of a large filter cake. This has been observed in previous tests [5]. Ideally, the stationary filter needs to be isolated as soon as possible to prevent the buildup of filter cake.

During the second 100-hour test, the control scheme was more mature. The necessary control constraints had been identified and were implemented. This all but eliminated tripping the system interlocks. Also, during this test period, greater care was taken to start the rotor as quickly as possible after initiating feed flow to minimize extended periods when feed pump pressure was applied to the rotary filter without filter rotation being established. This resulted in a higher initial flux that continued for the duration of the testing. The final control scheme used in the facility should include automatic rotary filter startup controls which are initiated when adequate pressure drop is established across the filters. Auto-starting the rotors will minimize extended periods when feed pump pressure is applied to the filters prior to rotation being established.

Filters not being run need to have mechanisms that ensure individual filters can be hydraulically isolated to prevent deadheading filters. The current deployment design includes manual isolation valves for each filter. Manual valves will require administrative procedures directing field operators to perform complex valve manipulation during startup to minimize deadhead time on each filter. Also, rotor interlocks will lead to an extended deadhead condition. Automatic isolation valves operated just prior to filter rotation is ideal. This would allow each individual filter being started in a sequence to remain isolated until just before they are brought online (rotor started). Filter rotors that interlock would be isolated immediately upon interlock rather than remaining online until a field operator could be dispatched to isolate the offending filter.

Incorporation of an automatic valve in the filter filtrate lines to allow isolation of individual filters and aid in filter startup is also recommended. The ability to isolate the filtrate lines will allow for individual startup of the filters as well as the ability to isolate a damaged or unneeded filter. Filtrate line isolation is also necessary to prevent reverse flow through the filter disks.

The amount of vibration on the filter is the single most important factor in filter lifetime. Filter vibration would change noticeably during a test as the system temperature changed. It was presumed that the increase in temperature during operation moved the motor relative to the filter and changed the alignment. This will most likely carry over to deployment, where operational, as well as atmospheric changes in temperature will affect the alignment of the motor and filter sets.

To facilitate proper alignment in deployment, the filter should ideally be tied directly to the motor. The motor mount design should include independent fine adjustment and the shaft design should provide enough room for the mounting of alignment equipment.

As a result of this testing, the basis for the field deployment control system has been developed and tuned. Early completion of the control scheme will significantly reduce the effort required during startup for actual waste processing. The layout of the test facility not only gave an indication of the hydraulic performance but also highlighted several areas of potential improvement of the rotary filter system in deployment.

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