Strategies for Instrumentation and Control of Thickeners and Other Solid-Liquid Separation Circuits

Instrumentation and Control of Sedimentation Equipment

Abstract

Some of the process variables that are commonly monitored on a thickener are torque, rake height, bed level, bed pressure, feed rate and density, underflow rate and density, settling rate, and overflow turbidity. Many of these are easily measured, while some can be difficult. Combining these signals into a coherent control strategy requires forethought and an understanding of the fundamentals of thickener operation. A wide variety of control strategies have been implemented on thickeners, using various combinations of sensors.

In recent years improved flocculants, higher throughput rates per unit area, and desired higher density underflow concentrations have required the development of better control strategies to successfully operate sedimentation equipment. This has been complicated by plant expansions that have placed increased loads on existing sedimentation equipment. Successful control strategies consider the process goals, plant fluctuations, sensor reliability, and system response times.

A historical review will be discussed followed by discussion of the latest developments in sensors, control equipment, and control strategies.

Introduction

Thickeners are used for increasing the solids content of a slurry. The general objectives are clean overflow and maximum solids concentration in the underflow. Flocculants are typically used to agglomerate the solids to increase the settling rate and improve the overflow clarity. Thickeners generally operate continuously with very high on-line availability. They are used in a wide variety of industries, and in numerous applications.

Thickener control has a number of complexities such as varying feed characteristics. Changes in feed concentration, solids specific gravity, particle size distribution, pH, temperature, and reaction to flocculant can all contribute to variations in performance. Accurate information about what’s happening inside the thickener is difficult to get. In addition, various phenomena such as “sanding” and “islands” can be difficult to interpret from the data.

There are two independent variables, flocculant rate and underflow rate, which are typically used for control. A third, the feed rate, is generally used only in an emergency to avoid impacting plant production. The dependent variables include rake torque, underflow density, overflow turbidity, solids interface level (bed depth), solids inventory (bed mass), solids settling rate and underflow viscosity.

Historically, most control schemes have used one or two of the dependent variables to control the independent variables. For example, using underflow density to control the underflow pump rate and solids settling rate to control the flocculant rate. Another possible scheme is to use the bed pressure to control the underflow rate and bed level to control the flocculant rate. Any control scheme is limited by the range of conditions that it can recognize and to which it can respond. None of them so far have been able to resolve all of the possible inputs in to specific conditions and react to them. Nor are they able to cope with instrument failure. For example, the two control schemes described above don't consider the rake torque and both can have problems from high torque if the feed particle size distribution suddenly becomes coarser.

Various algorithms have been used to control thickeners with varying degrees of success. Rule based expert systems have been developed for use on thickeners since the early days of computerized control systems, but have been cumbersome for implementation, troubleshooting, modification, and tuning. With the recent developments in expert control software, these issues have been greatly simplified.

Historical Review

Review Priday paper

A few case histories?

Instrumentation

Torque

Rake torque is an indication of the force necessary to rotate the rakes. Higher rake torque is aqn indication of higher underflow density or deeper mud bed, although it can also be caused by a higher fraction of coarse material as well as a number of other phenomon, such as islands.

Rake torque measurement is usually provided by the thickener manufacturer. Typical methods involve load cells, motor power measurement, hydraulic pressure, or mechanical displacement against a spring. They are all generally reliable and reasonably accurate if set up correctly. The type supplied generally depends on the manufacturer and the type of drive supplied. For example, if a hydraulic drive is used, then hydraulic pressure is the best method to use for torque measurement.

Rake height

Rake lifting devices are frequently used to limit the torque and enable the rake to continue running during upset conditions. It is generally desirable to prevent the rake drives from running extended periods at torques above 50-60%, to prevent accelerated wear. Lifting the rakes a small distance is usually effective at reducing the torque. Because of this, using the torque indication in a control strategy must also consider the rake height in order to effectively control the thickener.

Rake height indicators are also typically supplied by the thickener manufacturer. The two most common methods are ultrasonic and a potentiometer with a reeling cable. Both are reliable and accurate.

Bed level

There are several general types of bed level detection; ultrasonic, nuclear, float and rod, and reeling (with various sensors). Each has it's advantages and disadvantages, which are discussed below. There is not a standard bed level sensor that we can recommend for all applications.

Ultrasonic bed level sensors work by sending a pulse down from just under the surface, which in theory bounces off the bed surface back to the receiver. Elapsed time is used to calculate the distance. Advantages are non-interfering location, measures over a large span, and relatively inexpensive. The downside is that they do not work on all applications. If the overflow is cloudy, it can interfere with the transmission or causes too much reflection to give a reliable signal. Using them on concentrate thickeners has proved to be particularly troublesome. Manufacturers are Milltronics and Royce.

Nuclear work be either sensing background radiation level or attenuation between a source and detector, depending on whether the solids have a natural background radiation level. If the ore changes from having radiation to not, it will be problematic. Advantages are that it is relatively reliable when properly applied. Downside is that it measures over a limited range, interferes with the rakes (they offer a hinged version that will swing out of the way when the rakes pass by), and is relatively expensive. Manufacturer is Amdel.

Float and rod types work with a ball with a hollow sleve that slides up and down on a rod. The ball can be weighted to float on top of the bed of solids. Subject to fouling and sticking, and can be installed and measure only in the area above the rakes. Relatively inexpensive. Manufacturer is Gems and others.

Reeling devices work by dropping a sensor down on a cable, and sensing the bed level by optical or conductivity sensors. In theory they are nonfouling and get out of the way of the rakes, but in practice, stories abound of sensors wrapped in the rakes and many plants won't consider them.

Reliable and can cover a large range. Midrange price. Manufacturers are Zellweger and Outokumpo.

Bed pressure

Because of the constant liquid level, the pressure at the bottom of the thickener is an indication of the overall specific gravity in the tank. If the liquor specific gravity is constant, The overall specific gravity is an indication of the amount of solids in the tank and can be converted into a rough solids inventory. This can be a very effective tool for thickener control. Because of relative height to diameter ratios, it is considered somewhat less useful for very large diameter thickeners.

Differential pressure sensors are used to measure the bed pressure, leaving one leg open to the atmosphere to compensate for barometric pressure variations. Care must be taken in the installation to minimize plugging with solids. This is frequently done by tilting the tank nozzle on which the DP cell is mounted downwards from the sensor so that solids tend to settle away from the sensor. A shutoff valve and a water flush tap are also recommended to allow easy maintenance.

Flow rate

Flow rates for feed and underflow lines are usefull, particularly when combined with density measurements in order to generate solids mass flow rates. Since flocculant is usually dosed on a solids mass basis, knowing the mass flow rate is very useful for flocculant control, providing a fast response system.

Since the streams being measured are usually slurries, the flow rate is usually measured by either magnetic flow meters or Doppler types. As long as these instruments are properly installed in suitable straight pipe sections, avoiding air if possible, they are accurate and reliable.

Density

Nuclear gauges.are the norm for density measurement. It should be noted that there are now some types that use very low level sources that do not need nuclear licensing, reducing the hassle of using these. Density gauges should be recalibrated regularly, roughly every 6 months, as they are subject to drift.

Small applications may be able to use coroilis meters to measure both mass flow and percent solids.

Settling rate

The settling rate in the feedwell is a good indication of the degree of flocculation, and can be used to maintain consistent flocculation over widely varying feed conditions. A settleometer is a device which automatically pulls a sample from the feedwell and measures the selling rate. These are available through Ciba. In most applications they require regular maintenance to maintain consistent operation.

Overflow turbidity

Overflow turbidity can be used to control flocculant or coagulant. There is some significant lag time between the actual flocculation and when the liquor reaches the overflow where the sensor is typically positioned, so these are generally used as alarms or for trim only. In most applications they require regular maintenance to maintain consistent operation.

Control Architecture and Equipment

Normally thickeners are part of an integrated control system where the objective is to remotely start and stop the equipment, monitor operating conditions and performance, stabilize operations based on operating and feed conditions and lastly, optimize performance based on economics and/or operational goals.

Tools to accomplish these goals include programmable logic controllers (PLC's), distributed control systems (DCS's) and expert control systems.

Programmable Logic Controllers are normally used to perform starting and stopping functions in processing plants. They do have the ability to also implement continuous control loops but this use is only used minimally.

Distributed Control Systems are the workhorse of plant control systems and normally are used to coordinate all the monitoring of process data and the subsequent stabilizing control of important process parameters. Specifically, for thickeners, monitored process parameters might include feed flowrate, overflow flowrate, overflow turbidity, underflow density, underflow flowrate, rake position, rake power and torque, flocculent dosage rate, bed level, and bed mass.

Stabilizing control loops might include flocculent dosage rate, underflow density, or underflow flowrate.

Control Strategies

Process goals

Challenges particular to sedimentation equipment

Strategies

There are two general flocculant dosing control methodologies: basing it on feed solids mass flow or off feedback from a sensor on the thickener. Mass flow is consistent and reliable, but not sensitive to changes in the feed solids. If a plant runs consistently, this can work very well and operators can make any needed adjustments. If the plant operation is not very consistent or tighter control is desired, then feedback control can be implemented using clarometers, bed level, underflow density, or turbidity. These can be used alone or as a trim on a mass flow dosage.

Strategies

Expert Control System
Generic Thickener
Control Strategy Outline

Thickener circuit - Thickener supervisor

The thickener supervisor monitors the performance of the thickeners in the tailings dewatering circuit and specifically controls polymer dosage and discharge rates to each thickener in the circuit. The supervisor can also allocate feed among the thickeners that are online. Table 1 shows a list of process measurements and control actuators employed by the thickener supervisor.

Table 1 - Thickener supervisor measurement and control parameters

Process Parameter	***Process Measurement***	***Control***

		Actuator
Feed rate	Mag flowmeter	
Feed distribution	Gate valve position	Gate valve position
Underflow discharge rate	Mag flowmeter	Pump speed
Underflow density	Nuclear density meter	
Bed pressure	Pressure transducer	
Flocculant feed rate	Flowmeter	Metering pump
Rake torque	Torque transmitter	
Water overflow rate	Flowmeter	

Every five minutes the thickener supervisor determines the appropriate control actions through the following decision tree:

Evaluate for emergency response situations: These are situations that require immediate attention. It is assumed that these conditions, if not addressed, would lead to a process emergency.

1. Check the current drawn by the underflow pump. If the current is too high, decrease the load on the pump by
    - reducing flow through the thickener; or
    - reducing flocculant rate.
2. Check the underflow density. If the density is too high, decrease the polymer dosage.
3. Evaluate the torque on the rake. If the torque is high, increase the pump speed.
4. Check the sludge level in the thickener. If the level is dropping rapidly, increase the pumping speed and decrease polymer dosage.

Although multiple emergency conditions may exist, the thickener supervisor will only take one control action every 5 minutes while in “emergency” status. The emergency conditions will be handled in the same order as they are listed. For example, if the rake torque is high AND the sludge level is dropping quickly, the thickener supervisor will only respond to check the rapidly rising torque by increasing the discharge rate. While the increased pumping rate will also mitigate the bed level situation, the thickener supervisor is only responding to the highest priority situation. This prevents multiplying (or masking) the effects of control actions by responding to multiple emergency conditions with similar or conflicting remedies.

Optimize thickener performance
If no "emergency" conditions exist then the thickener supervisor seeks optimum performance. To obtain optimum performance, two targets are used.

1. An underflow density target is used to ensure optimum solids content in the tailings impoundment, and optimum water reclaim for the mill.
2. A bed level target is used to obtain optimum loading in the thickener without overloading the drive mechanism.
3. Bed pressure is used as an indication of solids inventory. This helps the system to determine whether a high bed level is the result of decreased settling rate or increased solids inventory.

4. In some cases, a drive torque target is used as an indication of acceptable underflow rheology.

Table 2. Optimizing Control Actions

Underflow Density	***Bed Level***	***Bed Pressure***	***Polymer Addition***	***Underflow Pump Speed***
above target	above target	rising	increase	increase
above target	above target	steady	increase	increase slightly
above target	above target	falling	no action	increase slightly
above target	on target	rising	no action	increase
above target	on target	steady	no action	increase slightly
above target	on target	falling	no action	no action
above target	below target	rising	decrease	increase
above target	below target	steady	decrease	increase slightly
above target	below target	falling	decrease slightly	no action
on target	above target	rising	increase	increase
on target	above target	steady	increase slightly	no action
on target	above target	falling	increase slightly	no action
on target	on target	rising	no action	no action
on target	on target	steady	decrease slightly	no action
on target	on target	falling	decrease slightly	decrease slightly
on target	below target	rising	decrease	increase
on target	below target	steady	decrease	no action
on target	below target	falling	decrease slightly	no action
below target	above target	rising	increase	no action
below target	above target	steady	increase	decrease
below target	above target	falling	decrease slightly	decrease
below target	on target	rising		
below target	on target	steady	no action	decrease
below target	on target	falling	decrease slightly	decrease
below target	below target	rising		
below target	below target	steady	decrease slightly	decrease
below target	below target	falling	decrease	decrease

Comments

These are the basics. The expert strategy is simple: Bed level is assumed to be controlled by polymer dosage, and underflow density by pumping speed. Bed pressure is taken as an indication of solids inventory.

Earlier versions of thickener rules were based on rate-of-change. The target approach seems more consistent with G2 installations for grinding and flotation, but I'm open to suggestions. Certainly some emergency situations are best detected based on rapid rise or fall of a parameter, rather than its absolute value.

Based on Ron's analysis of OCI, paste thickening seems to be more complex in that it adds rake drive torque, liquor specific gravity, bed pressure, and pipeline backpressure as inputs, and rake tip speed as an output. Monitoring/alarming of levels in polymer feed tanks is probably best left to the DCS, if possible.

It seems there is more we can do. For example, in multiple thickener operations, the expert system could divert flow to match settling capacity based on observations of bed level and pressure.

Paste Strategy

Expert Control System
Paste Thickener
Control Strategy Outline

Object-Oriented Control

The control strategy for the paste thickener is contained within the Knowledgescape expert control software. Knowledgescape uses an object-oriented structure for it's rulebase, rather than the more conventional sequential method. In Knowledgescape, each process element is an "object" in the software. The objects have attributes that describe the state of the process element. Objects or groups of objects can be contained within larger objects, also with attributes. In the tertiary thickener control strategy, as an example, the bed-level sensor is represented by a software object with attributes of measured bed position, high limit, low limit, and rate-of-change (among others). The sensor is contained within a larger object called "thickener," comprised of the process sensors, the flocculant dosing system, the thickener drive mechanism and the underflow pump(s). The rules that make up the decisionmaking function of the expert system are attached to the software object they are concerned with, and are executed according to schedules also associated with the object. Table 1 shows a list of process measurements and control actuators employed by the thickener strategy.

Table 1 - Thickener strategy measurement and control parameters

Process Parameter	***Process Measurement***	***Control Actuator***
Feed rate	Mag flowmeter	
Feed density	Nuclear density meter	
Rake speed		Solenoid valve(s)
Underflow discharge rate	Mag flowmeter	Pump speed
Underflow density	Nuclear density meter	
Bed pressure	Pressure transducer	
Flocculant feed rate	Flowmeter	Metering pump
Rake torque	Torque transmitter	
Liquid specific gravity	Refractometer	
Liquid overflow rate	Flowmeter	

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Thickener Control Strategy

Every five minutes the thickener supervisor determines the appropriate control actions through the following decision tree:

Evaluate for emergency response situations: These are situations that require immediate attention. It is assumed that these conditions, if not addressed, would lead to a process emergency, or at least a serious process upset.

1. Check the current drawn by the underflow pump. If the current is too high, decrease the load on the pump by
   a) reducing flow through the thickener; or
   b) reducing flocculant rate.
2. Evaluate the torque on the rake. If the torque is high, increase the underflow pump speed.
3. Check the solids inventory. If the solids inventory is too high, increase underflow pump speed.
4. Check the sludge level in the thickener. If the level is too high, increase flocculant dosage. If the level is too low, decrease dosage.
5. Check the underflow density. If the density is too high, decrease the flocculant dosage.

Although multiple emergency conditions may exist, the thickener supervisor will only take one control action every 5 minutes while in “emergency” status. The emergency conditions will be handled in the same order as they are listed. For example, if the rake torque is high AND the sludge level is high, the thickener supervisor will only respond to correct the high torque by increasing the discharge rate. While the increased pumping rate will likely mitigate the bed level situation as well, the thickener supervisor is only responding to the highest priority situation. This prevents multiplying (or masking) the effects of control actions by responding to multiple emergency conditions with similar or conflicting remedies.

After determining the proper setpoint change according to the rules, the expert system checks that the changes will be within the operating parameters for the equipment. If a setpoint change would drive the parameter outside the limits, the amount of change is reduced. If no change is possible because the parameter is already at a limit, the expert system informs the operator, who must then make adjustments outside the scope of the expert system’s control.

Optimize thickener performance: If no "emergency" conditions exist then KnowledgeScape begins to seek optimum performance. To obtain optimum performance, three operational targets are used.
1. Drive torque is used as an indication of slurry rheology to provide appropriate mechanical characteristics for mine backfill.
2. A bed level target is used to detect changes in settling rate requiring adjustment of the flocculant dosage.
3. A density target is used to ensure optimum solids content in underflow, and optimum liquor recovery for the circuit.

The deviation from the drive torque target is evaluated along with the rate of change in solids inventory and drive torque to determine appropriate setpoint changes in underflow pumping rate and rake speed. The system also evaluates the position of the solids bed to determine changes in flocculant dosage. In a second tier of optimizing control, the system evaluates the deviation from the underflow density target, and uses this value in connection with a calculation of the solids inventory rate-of-change to select setpoint changes for underflow pumping rate and rake speed.

It is apparent that these control strategies can initiate conflicting control actions, resulting in canceling effects or, worse, a cycling behavior as the rules react to the effects of each other's control actions. To prevent this, control actions are linked to fuzzy control logic functions that temper the control response based upon the difference between the observed performance and its target. This causes the system to "home in" on the target, rather than cycle alternately above and below it.

Knowledgescape reports every control action to the operators. The messages explain the reason for the action and the magnitude of the change. This allows the operator to assess the circuit's (and Knowledgescape's) performance. The message-reporting process also serves to inform the operator of process limitations that are preventing the circuit from performing at its optimum level.

Knowledgescape's effect is to push the paste thickener to its optimum performance without catastrophic overload. When a problem is identified the system makes timely adjustments to prevent a process upset. When the problem is corrected, Knowledgescape resumes its pursuit of the performance targets. Because of its constant monitoring and frequent decision-making, the system relentlessly pursues the highest performance possible from the circuit.

Table 2.—Flocculant Ratio Optimizing Actions

Pulp Level	***Flocculant Ratio***
Increasing	Increase
Steady	Decrease
Decreasing	Decrease

Table 3.—First level Optimizing Actions

Inputs			Outputs	
Solids Inventory	***Drive Torque Change***	***Drive Torque Value***	***Underflow pump speed***	***Rake Speed***
Increasing	Increasing	Above Target	Increase	Increase
Increasing	Increasing	Below target	Increase	No change
Increasing	Increasing	On target	Increase	Decrease
Increasing	Steady	Above Target	Increase	Increase
Increasing	Steady	Below target	Increase	No change
Increasing	Steady	On target	Increase	Decrease
Increasing	Decreasing	Above Target	Increase	Increase
Increasing	Decreasing	Below target	Increase	Decrease
Increasing	Decreasing	On target	Increase	Decrease
Steady	Increasing	Above Target	Increase	Increase
Steady	Increasing	Below target	Increase	No change
Steady	Increasing	On target	No change	Decrease
Steady	Steady	Above Target	Increase	Increase
Steady	Steady	Below target	No change	Decrease
Steady	Steady	On target	Decrease	Decrease
Steady	Decreasing	Above Target	Increase	Decrease
Steady	Decreasing	Below target	No change	Decrease
Steady	Decreasing	On target	Decrease	Decrease
Decreasing	Increasing	Above Target	Increase	Increase
Decreasing	Increasing	Below target	Decrease	Decrease
Decreasing	Increasing	On target	Decrease	Decrease
Decreasing	Steady	Above Target	Increase	Increase
Decreasing	Steady	Below target	Decrease	Decrease
Decreasing	Steady	On target	Decrease	Decrease
Decreasing	Decreasing	Above Target	Decrease	Decrease
Decreasing	Decreasing	Below target	Decrease	Decrease
Decreasing	Decreasing	On target	Decrease	Decrease

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Table 4.—Second level Optimizing Actions

Inputs		Outputs	
Underflow density	***Solids inventory***	***Underflow pump speed***	***Rake speed***
Above target	Increasing	Increase	Increase
On target	Increasing	Increase	Decrease
Below target	Increasing	Decrease	Decrease
Above target	Steady	Increase	Increase
On target	Steady	Decrease	Decrease
Below target	Steady	Decrease	Decrease
Above target	Decreasing	Increase	Increase
On target	Decreasing	Decrease	Decrease
Below target	Decreasing	Decrease	Decrease

Expert Control

Advanced Thickener Control

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Abstract

Thickener control is a complex process and a workable expert control system that could be applied across a range of applications has not been available. With the recent developments in expert control software, combining the latest process control technologies with new artificial intelligence computing tools, thickener control can be greatly simplified.

This paper details the implementation of a thickener expert control system at Cortez Gold in Nevada using KnowledgeScapetm[tm] expert control software. Input by a number of thickener experts was used to devise a robust rule based control scheme. The benefits realized from the expert control systems so far have been tighter control of output objectives (e.g. underflow density) and fewer emergency conditions in the thickener. The system architecture and some of the design challenges are discussed.

1. Introduction

Thickeners are used for increasing the solids content of a slurry. The general objectives are clean overflow and maximum solids concentration in the underflow. Flocculants are typically used to agglomerate the solids to increase the settling rate and improve the overflow clarity. Thickeners generally operate continuously with very high on-line availability. They are used in a wide variety of industries, and in numerous applications.

Thickener control has a number of complexities such as varying feed characteristics. Changes in feed concentration, solids specific gravity, particle size distribution, pH, temperature, and reaction to flocculant can all contribute to variations in performance. Accurate information about what's happening inside the thickener is difficult to get. In addition, various phenomena such as "sanding" and "islands" can be difficult to interpret from the data.

There are two independent variables, flocculant rate and underflow rate, that are typically used for control. A third, the feed rate, may be used only in an emergency to avoid impacting plant production. The dependent variables include rake torque, underflow density, overflow turbidity, solids interface level (bed depth), solids inventory (bed mass), solids settling rate and underflow viscosity.

Historically, most control schemes have used one or two of the dependent variables to control the independent variables. For example, using underflow density to control the underflow pump rate and solids settling rate to control the flocculant rate. Another possible scheme is to use the bed pressure to control the underflow rate and bed level to control the flocculant rate. Any control scheme is limited by the range of conditions that it can recognize and to which it can respond. None of them so far have been able to resolve all of the possible inputs in to specific conditions and react to them. Nor are they able to cope with instrument failure. For example, the two control schemes described above don't consider the rake torque and can have problems from high torque if the feed particle size distribution suddenly becomes coarser.

Various algorithms have been used to control thickeners with varying degrees of success. Rule based expert systems have been developed for use on thickeners since the early days of computerized control systems, but have been cumbersome for implementation, troubleshooting, modification, and tuning. With the recent developments in expert control software, these issues have been greatly simplified.

2. Expert control systems and use on thickeners

Expert control software is almost always used as a shell on top of a PLC or DCS based stabilizing control system. The system architecture is based on a three component control pyramid with instrumentation as the base, stabilizing control as the next layer, and expert control on top of the stabilizing control. The expert control is used to modify the setpoints used by the stabilizing control.

This pyramid structure allows very clean, easily adjusted control logic compared with trying to include all of the rules into the stabilizing control. This also allows expert control to be integrated with existing control systems.

KnowledgeScape^{tm} expert control software has been used for the installations referenced is this paper. KnowledgeScape^{tm} software, is a process control software package for automating, stabilizing and optimizing any process. It runs under Windows NT and utilizes computing resources across a local network to optimize internal performance as well as the external process to which it is assigned.

> KnowledgeScape^{tm} software uses English-like syntax to create control and optimization rules, making the control strategy easier to access, understand and modify. Object-oriented representation makes it easier for users to model the real world, allowing them to address plant control needs without advanced programming skills. KnowledgeScape^{tm} software has many modules for configuring communications, writing rules, creating fuzzy sets, creating models for predictions, creating optimizers for processes, trending data, viewing data, controlling computing resources, and managing the KnowledgeScape^{tm} environment.

The thickener expert control program does not use all the advanced artificial intelligence tools available in KnowledgeScape^{tm} software but it does make extensive use of fuzzy logic. Fuzzy logic allows the use of terms such as “normal”, “high”, or “very high” that can be applied to variables, similar to how an expert operator would describe them. This greatly simplifies interpretation and programming of rules, and provides a much smoother response to system changes. It also helps speed tuning and provides more operational flexibility.

3. Instrumentation

There are a variety of instruments that can be used to gain insight into what’s happening inside a thickener. Their use in control systems is critical to the proper functioning of the system. Most of the common instruments used in thickener control are reviewed briefly below.

The drive torque is probably the single most important signal from a thickener. If the torque is allowed to rise too high, the thickener rakes will stall and the unit will have to be shut down and cleaned out. Conversely, if the torque is very low, a higher underflow density could probably be generated.

Many thickeners use a rake lift in order to provide a margin of safety and operating flexibility. Operating at high torque on the drive can cause high wear rates on the drive and compromise the drive lift. A lift is used to limit the torque seen by the drive, minimize shutdowns, and maximize drive life. A common arrangement is for the lift to actuate at torque's above 50% and to automatically lower at torque's below 30%. A lift position transmitter is used to transmit the rake position. The rake lift height must be considered when interpreting the rake torque.

Feed and underflow densities are typically measured using nuclear density meters. A density measurement is relative to the material being processed; some materials will easily thicken to 70 wt % while others would appear quite solid at 40 wt%.

Feed and underflow flow rate can be measured using a variety of flowmeters. Flow and density information are often combined to calculate a solids rate or mass flow rate. This can be used for flocculant dosage control. There are many different types of flowmeters and the type of flowmeter must be matched to the application for best performance.

Bed level is an important indicator of performance. If it is allowed to rise too high, the overflow turbidity will be affected; too low and the underflow density will be affected. In general, deeper beds result in higher underflow densities. There are several types of instruments for measuring bed level including ultrasonic, ball float, and cable reel devices. Some of the factors that affect instrumentation selection are scaling, temperature or chemical compatibility, range limitations and turbidity.

Bed mass is generally indicated by the use of a pressure transmitter mounted near the underflow outlet. The pressure signal can be compared to a water-only pressure to deduce a solids inventory. Maintaining a consistent solids inventory can greatly simplify thickener operation, however, there are many times when it is advantageous to build up inventory in the thickener due to downstream process considerations.

Settleometers were developed to measure the settling rate of flocculated solids. They typically sample flocculated feed from the feedwell and control the flocculant flow rate to maintain a consistent settling rate.

Overflow turbidity is a measure of the clarity of the overflow. This is more of a concern in a clarifier instead of a thickener (where the overall objective is clean overflow, not high underflow density). Most thickeners have some practical limit on turbidity that works for their situation.

A typical P&ID incorporating these instruments is shown in Figure 1.

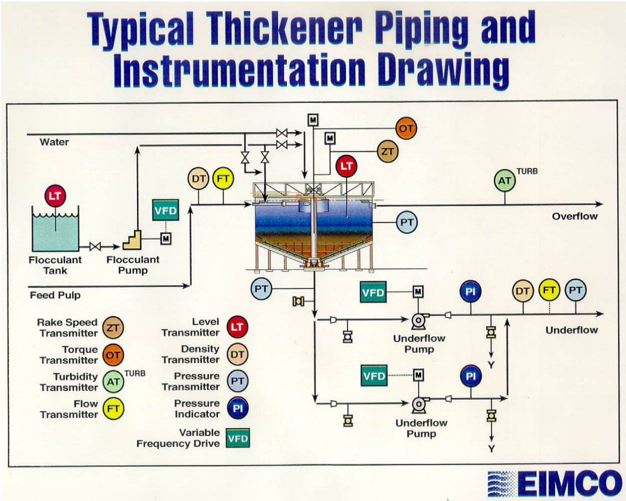

Figure1. Typical P&ID

4. Development of a standard expert control rule base for thickeners

The control strategy for the rules was developed through input from a number of thickener experts, all with many years of experience at thickener troubleshooting and operation. Reactive strategies to correct problem conditions in the thickener as well as proactive strategies with measures to prevent problems from developing were included. Programming the rules into an expert control system was done by engineers skilled at control programming. The result of the team effort went through many cycles of review and refinement to arrive at a finished product suitable for use across a broad range of applications.

For the rule base structure a hybrid combination of Tabular and Branch rule architecture has been used. The branch rule architecture consists of housekeeping rules such as; variable initialization, calculations, DCS control, set point handling, and status determination rules. The control decision rules are tabular groups of fuzzy rules. The tabular fuzzy rules allow a high degree of control flexibility through combining multiple variable conditions in to combined independent variable control decisions.

The fuzzy sets have also been configured to be self-scaling, so that they can automatically adjust to changing set point or output limits and operation strategies.

The rule structure priority first checks and responds to emergency conditions. If there are no emergency conditions, optimizing rules will execute to minimize flocculant use and maximize (or hold to a target) underflow density.

5. Specifics of Cortez Gold

A KnowledgeScape™ expert control system was installed at Placer Dome's Cortez Gold Mine Mill #2 concentration plant in Nevada. This plant is the lowest cost gold producer in the U.S.

The mill processing facility is designed for throughput of 9280 tons/day; all of which passes through the grinding thickener. The grinding is done by a 26-foot diameter SAG mill and a 16-foot diameter ball mill. The slurry flows into a surge tank for a one-hour cyanide leach to dissolve gold before entering the 65' diameter by 10' side depth EIMCO thickener. The thickener overflow goes to CIC (carbon in column) for gold recovery. The underflow goes to CIL tanks for continued leaching followed by CIL (carbon in leach) gold recovery.

The control objectives of this thickener were to maximize overflow flow rate and optimize underflow density around a target density. The rules also look down stream and upstream for input about the circuit load to determine whether the thickener needs to increase or decrease total throughput.

The overflow flow rate is maximized using a local control loop that regulates water addition to maintain the maximum overflow flow rate to CIC. The strategy seeks to dilute the feed slurry and wash out the dissolved gold to CIC for recovery.

T[illegible] slurry to the target density for optimum control of the CIL tanks. The underflow flow rate, flocculant addition, and feed flow rate are independent variables for the control strategy. The dependent variables are bed pressure (solids inventory), bed level, rake torque, underflow density, and pump amps.

Fuzzy logic rules control the independent variable set points based on the dependent variable relationships. Following is an example of a fuzzy logic rule group for underflow density control.

IF uf_density IS a_little_high THEN floc_add setpoint_change IS small_decrease

IF uf_density IS medium_high THEN floc_add setpoint_change IS small_decrease AND uf_flowrate setpoint_change IS small_increase

IF uf_density IS very_high THEN floc_add setpoint_change IS medium_high AND uf_flowrate setpoint_change IS medium_increase

The fuzzy sets were set up as shown in Figures 2 and 3, with the dependent variable states represented by overlapping forms that were appropriate for the physical relationship and the independent variables represented by separated right triangles.

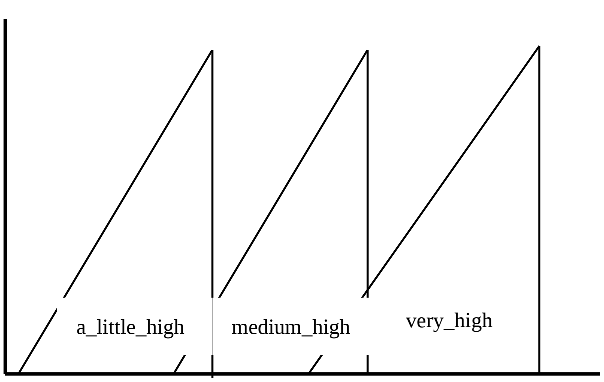

Figure 2. Dependent variable states for underflow density.

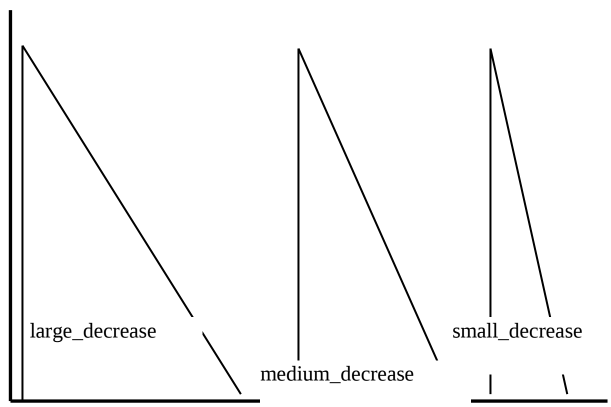

Figure 3. Independent variable states for flocculant subtraction set point changes.

The rule groups included all the necessary dependent variable states represented by the degree of magnitude desired (e.g. low, medium, high, very high, etc.). Each dependent variable state was represented on a fuzzy set graph and positioned in the desired range.

The magnitude and range over which the fuzzy variables respond can be easily tuned and adapted for specific applications by adjusting the size and overlap of the forms (triangles etc.) on the fuzzy set graphs.

6. Benefits

At the Cortez Mine Mill #2, the expert control system yields tighter underflow density control around the underflow density target and produces more consistent operation of the thickener without upsets.

The mill feed ore characteristics change three to six times a day. Variations in underflow density in the past have caused stratification and flow-through problems in the CIL circuit which have in-turn required the mill to cut back throughput.

The benefit of maintaining consistent thickener operation in changing ore conditions with less upsets and variation in output density has helped increase mill throughput and recovery and stabilized operation of downstream processes. Throughput in the mill has increased about 8-10%.

Even when they are running the thickener manually, operators tend to use the expert system for reference and for guidance in emergencies. The KnowledgeScape[tm] expert control system is proving to be a robust, flexible control system that can be configured for significant operational benefits.

The capability of KnowledgeScape[tm] to use neural network models, predictors and genetic algorithms to optimize operation around economic objectives such as reduced floc usage have not yet been activated for control. These artificial intelligence tools are proving to provide optimized control by exploiting control relationships not well understood by operators. To date, most of the optimization work has been concentrated on grinding and has been very successful. This work will continue to develop at Cortez and other installations now that these tools are available.

7. References

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