

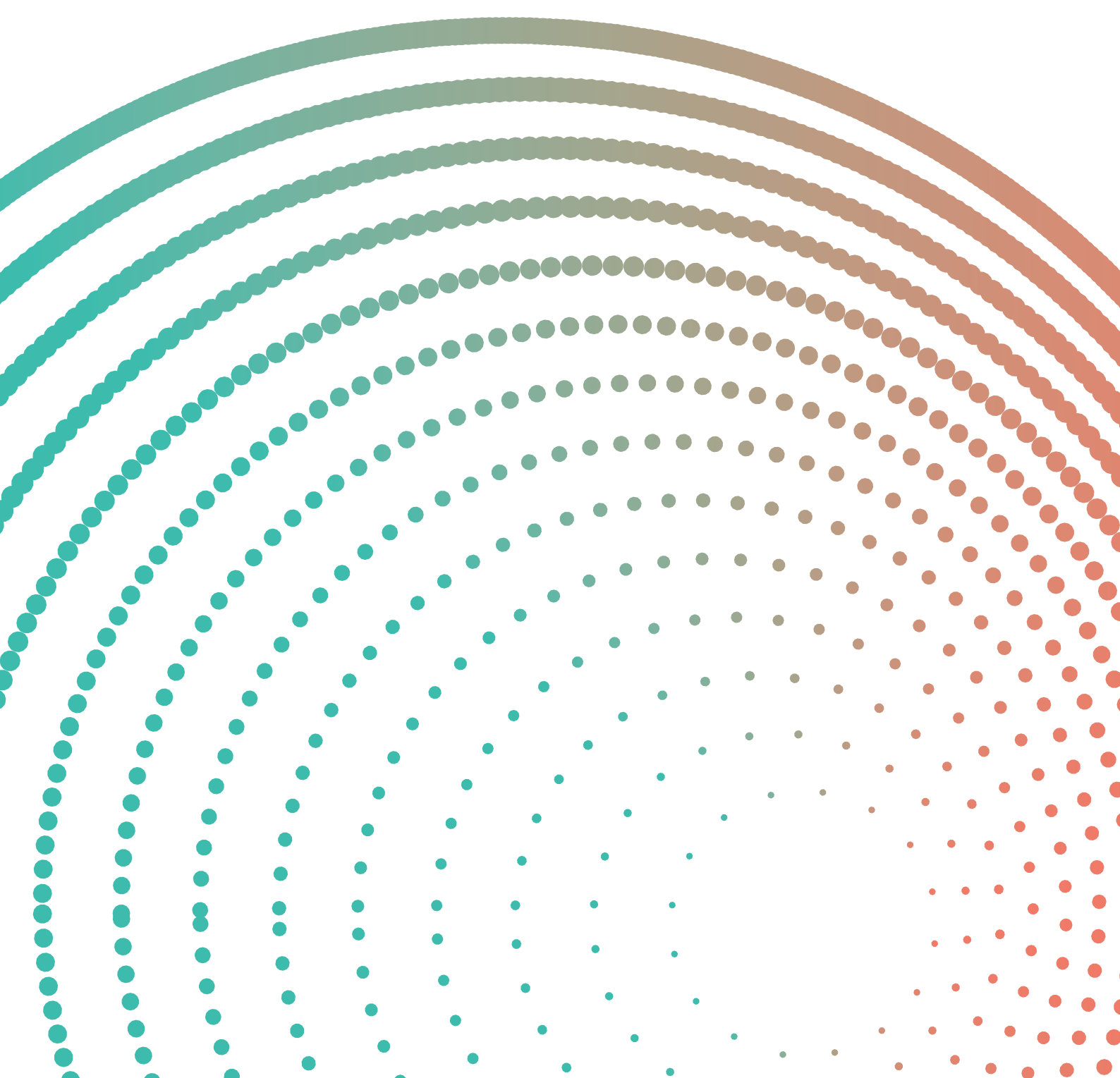
FloatStar

Flotation Control & Optimisation



Advanced Control

Process Optimisation



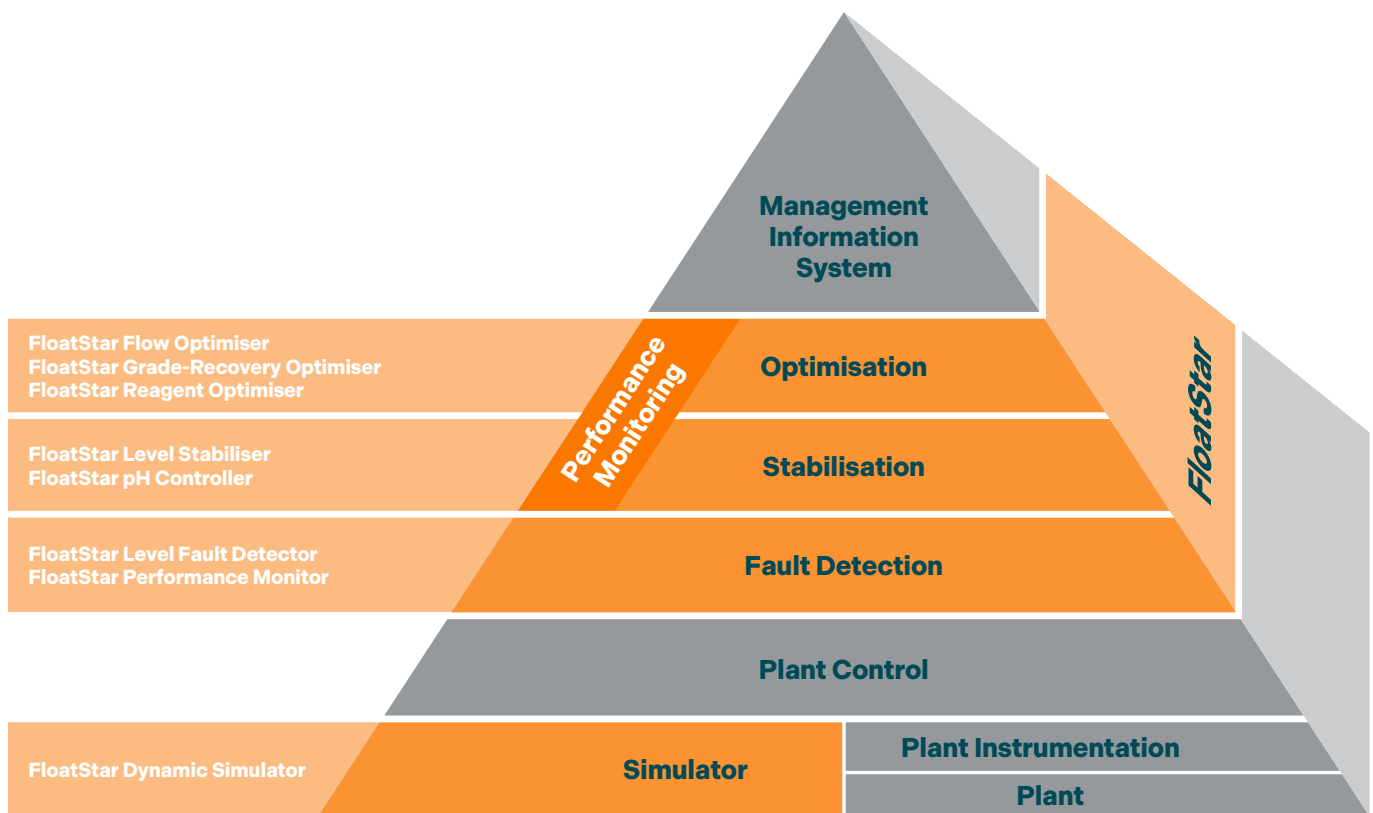
FloatStar Overview

Flotation is a complex process that is affected by a multitude of factors. These factors may be inherent in the circuit design, or in how the flotation plant is operated. Distributed by Molycop, the Mintek FloatStar suite of control modules utilises advanced process control to overcome design-related limitations and maximise circuit performance during operation.

As far as possible, the FloatStar control modules are designed to be implemented with little or no additional instrumentation. This modular approach ensures the design of a customised solution, specific to the objectives of each plant.

Furthermore, this approach allows for phased implementations that are useful both in assessing the benefit of the system, and in allowing plant personnel to be introduced gradually to any changes in operation (Change-Management).

The diagram below illustrates a bottom-up approach to flotation stabilisation and optimisation:



Stabilisation

Level Stabiliser

The FloatStar Level Stabiliser has been implemented on flotation circuits around the world. It has repeatedly been proven efficient in rejection of disturbances, and in rapid tracking of setpoints.

The main difficulty in controlling flotation levels is that they form part of a highly interconnected system. The control actions of one bank will therefore influence other banks and, unless handled correctly, disturbances will propagate through the circuit. This means that good level stabilisation control cannot be achieved by using controllers that only act locally. The top two figures on the right show how a disturbance will propagate through the circuit.

The FloatStar Level Stabiliser solves this problem, and is designed to provide the following benefits:

Fast setpoint tracking by:

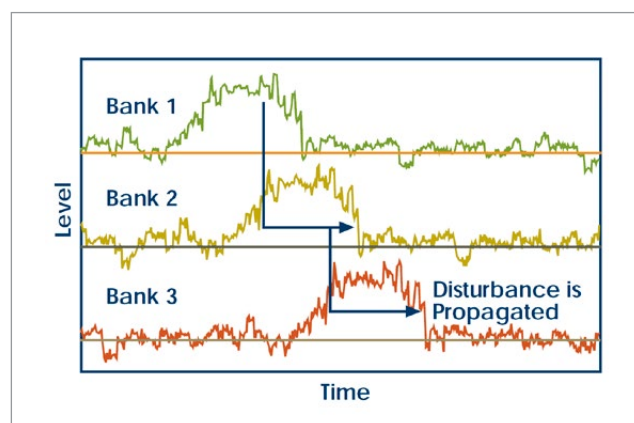
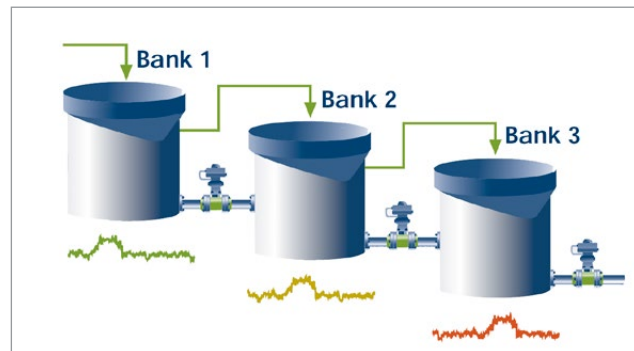
- Considering all levels simultaneously to eliminate interaction
- Rejecting disturbances quickly and efficiently throughout the entire circuit.

Reduced startup time:

- Typically a reduction from over 3 hours to under 1 hour in the time taken to stabilise the final tails grade.

Improved overall recovery:

- On numerous plants, processing a wide range of mineral types, the FloatStar Level Stabiliser has consistently increased recovery by between 0.5% and 1.3%
- On most minerals processing plants, the payback period is in the order of 1 to 3 months.

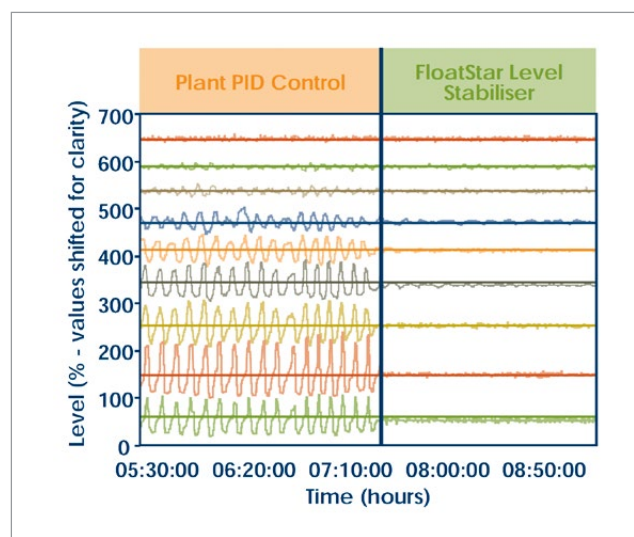


Case study

Performance testing, with a benefit analysis, has been performed on concentrator plants of several different mineral types. On-Off tests during normal operation, as well as benefit achieved during startups were assessed.

Comparison of controller performance The graph on the right shows a comparison of normal PID control to FloatStar Level Stabilisation. Worth noting is how, under PID control, the disturbances from the first banks are magnified further downstream. The control has visibly improved while the FloatStar Level Stabiliser was in operation. The general deviation from setpoint has decreased markedly, and changes to setpoint are tracked rapidly and without producing downstream disturbances.

The table below shows the Integral of Absolute Error (IAE) controller performance measure. The deviation from setpoint under FloatStar Level Stabiliser control is considerably lower than under normal plant PID control.

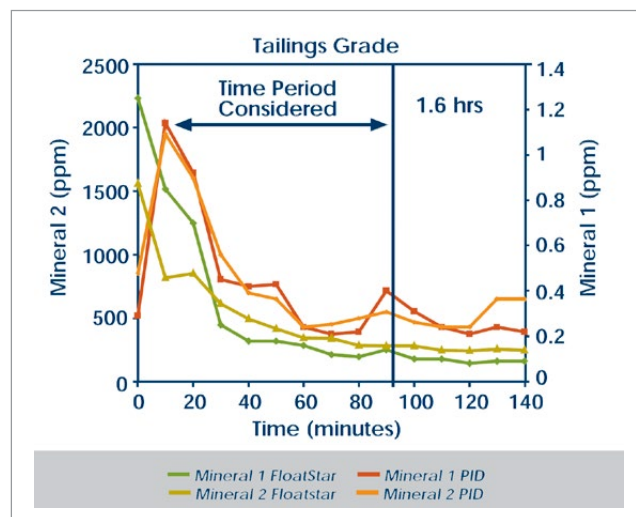


	Primary Rougher 1	Primary Rougher 2	Primary Rougher 3	Primary Rougher 4	Primary Rougher 5	Primary Rougher 6	Primary Rougher 7	Primary Rougher 8	Primary Rougher 9
IAE OFF	13.42	14.84	25.59	56.13	93.76	129.64	139.89	195.76	116.64
IAE ON	9.00	7.58	8.38	10.32	6.29	6.60	8.10	8.63	8.34

Benefit during startup

The plant used for this case study processed two different mineral types. Measurements were taken regularly while the plant was starting up, once under PLC PID control and once under FloatStar Level Stabiliser control. The graph on the right shows a comparison of the tailings grade measurements during the startup procedure. It is clear that the startup under FloatStar Level Stabiliser control stabilises more rapidly, and with lower tailings grades, than that using PID control.

The table below shows the quantitative economic evaluation of the savings achieved by using the FloatStar Level Stabiliser for circuit startup. A total savings of US\$7500 was achieved on each startup by using the FloatStar system.



Mass flow of tailings stream: 1975 tons/hr	
Time period of benefit/loss calculation: 1.6 hrs	
Cost of mineral 1: US\$ 350/oz	Cost of mineral 2: US\$ 1528/ton
Mineral 1 lost by PID control compared to FloatStar control: 0.2ppm	Mineral 2 lost by PID control compared to FloatStar control 250 ppm
Mass of mineral 1 lost 527g (18.6oz)	Mass of mineral 2 lost: 0.66 tons
Cost of mineral 1 lost US\$ 6500	Cost of mineral 2 lost: US\$ 1000
Savings by using FloatStar Level Stabiliser during startup: US\$ 7500	

Flow Optimiser

With the FloatStar Level Stabiliser providing circuit stability and rapid setpoint tracking, it then becomes possible to consider flotation optimisation.

The FloatStar Flow Optimiser controls circulating loads and mass pull in the flotation circuit. It is well known that circuit performance (grade and recovery) is strongly affected by these parameters. By stabilising circulating load and mass pull, it is possible to ensure consistent circuit performance.

The Flow Optimiser uses multivariable control techniques to continually optimise the numerous variables that affect circuit flows. Typically these are the level and air setpoints in different sections of the plant.

Depending on the circuit configuration and available instrumentation, the FloatStar Flow Optimiser can be used to control any of the following parameters:

- Mass pull rates
- Residence times
- Internal flowrates.

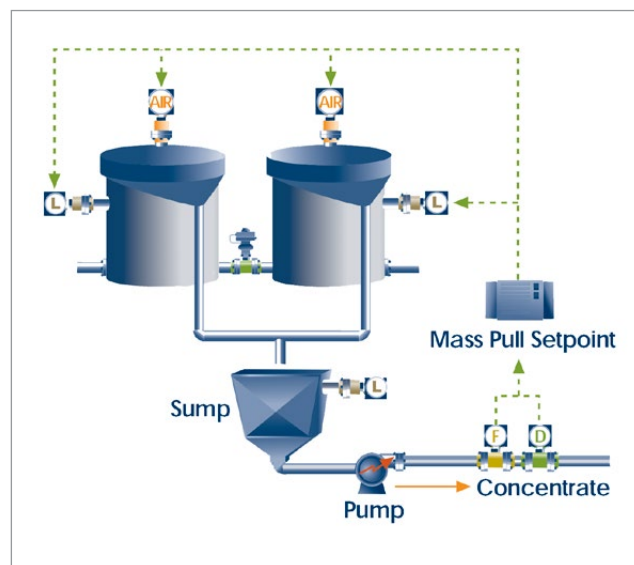
Controller	Required Equipment
Mass Pull Control	Flowmeter on Concentrate Line
	Densitometer on Concentrate Line
Residence Time Controller	None
Flow Controller	Flowmeter

Mass Pull Control

In order to obtain a constant mass pull from a flotation train, all of the banks that produce concentrate need to be set at the correct level and air setpoints, as these affect the mass pull achieved. The FloatStar Flow Optimiser makes use of multivariable techniques to achieve the desired mass pull rates from these banks, in the manner depicted by the image right:

By automatically adjusting the level and air setpoints on the final stages, the mass pull can be accurately controlled and maintained throughout changing ore conditions and circuit upsets, thereby ensuring tonnage targets.

Controlled Variable	Mass Pull
Measured Values	Density & Flowrate of Concentrate
Manipulated Variables	Level and Air Setpoints

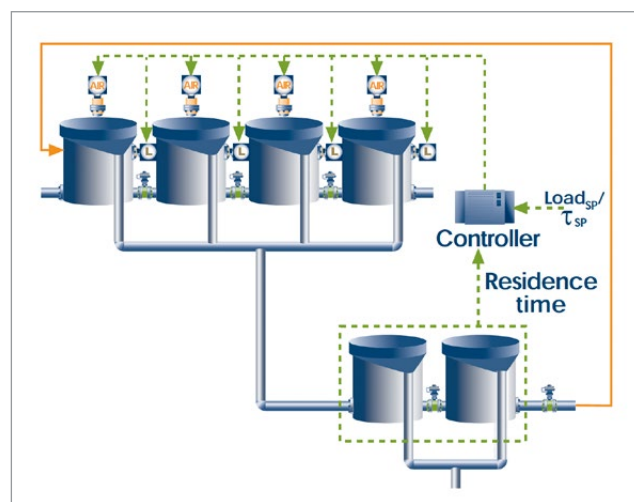


Residence Time/Re-Circulating Load Controller

The mechanics of flotation shows that there is a direct impact on recovery as the residence time changes.

It is possible with the FloatStar Flow Optimiser to control the inferred flow, and hence the residence time of a bank, to setpoint. The residence time (and re-circulating load in the case of a closed circuit) can be stabilised ensuring maximum efficiency of key flotation banks thereby improving overall circuit performance.

Controlled Variable	Residence Time
Measured Values	None - Values Inferred
Manipulated Variables	Air and Level Setpoints of Banks Supplying Concentrate



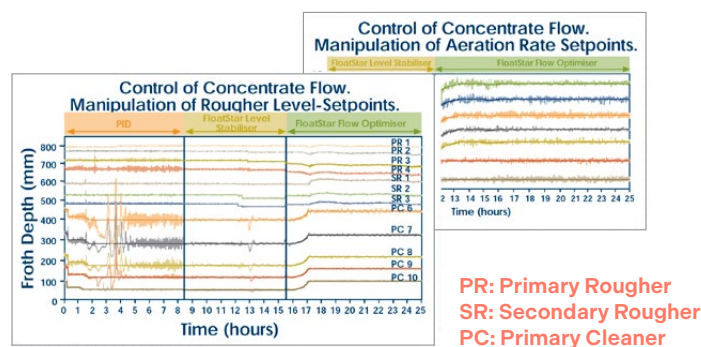
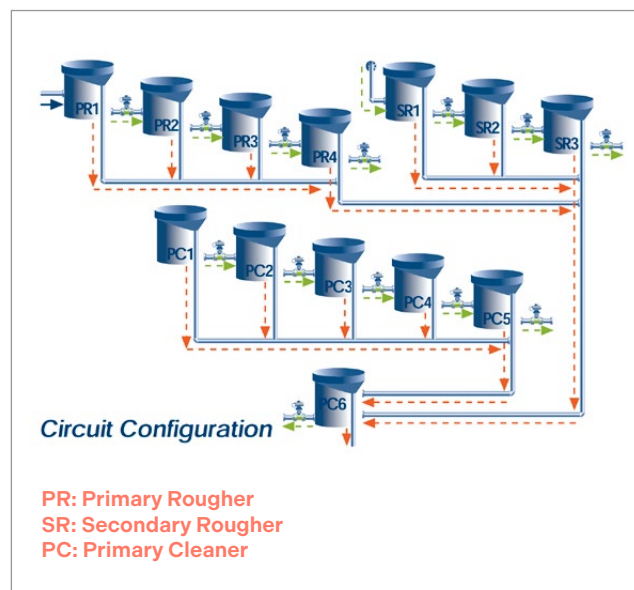
Case Study of implemented Residence Time controller

Consider the flotation circuit shown in the figure right which is currently employed by one of our clients. The aim is to control the residence time of PC6 by adjusting the setpoints of the banks supplying concentrate. The multivariable algorithm of the optimiser determines changes to the air and level setpoints.

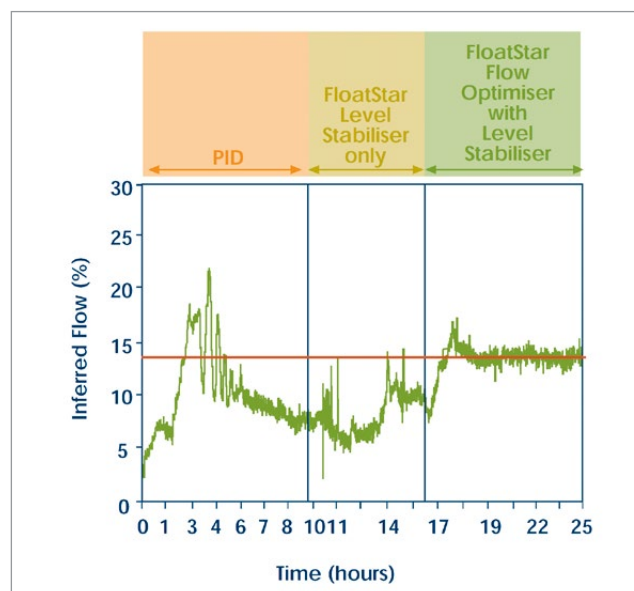
A special estimating filter based on available plant measurements is used to infer the flowrate through PC6 and hence estimate the residence time. With this estimation the optimising algorithm is able to adjust the level and aeration setpoints of the Roughers and Cleaners.

The graph right shows the inferred cleaner tailings flow over a 25-hour period, which is directly related to the residence time in the bank. Under normal PID control, it can be seen that there is virtually no control of the residence time.

However, when the Flow Optimiser is switched on, the tailings flow is rapidly and tightly controlled to setpoint. In this case, the Flow Optimiser manipulated both the aeration rates and level setpoints of relevant Rougher and Cleaner banks.



	Standard Deviation of Flow Error from Setpoint
PID	4.20
FloatStar	2.20
Flow Optimiser	1.44



Flow Controller

Another example of effective circuit optimisation is the control of a tailings flowrate in the cleaning stages. The level and air setpoints of the banks supplying concentrate are manipulated in order to obtain the desired tailings flowrate.

Controlled Variable	Tailings Flowrate
Measured Values	Flow Rate, or Inferred Flow Rate
Manipulated Variables	Air & Level Setpoints of Banks Supplying Concentrate

Additional features and benefits:

- The relative mass pull contributions from the different banks can be specified
- Operation of the circuit is steered away from bottlenecks (e.g. valves saturating)
- Built-in safety loops prevent limits from being violated.

The FloatStar Flow Optimiser has been successfully implemented on numerous flotation circuits with varying configurations and degrees of instrumentation and automation. The fast level setpoint tracking that can be achieved by the FloatStar Level Stabiliser further enhances the performance of the optimisation strategy.

Grade-Recovery Optimiser

With the increase in availability of online grade analysis, it is now possible to manipulate the flotation circuit operating conditions to optimise plant performance. Developed as a result of these

advancements, the FloatStar Grade-Recovery Optimiser provides continuous, online optimisation of circuit operation throughout fluctuating plant conditions.

Typically, flotation circuits aim to produce a concentrate grade of a specified quality, while recovering as much of the valuable mineral as possible. The behaviour of the circuit (ultimately the final grade and recovery) will be influenced by, amongst others, the:

- Level setpoints
- Aeration rates
- Bank residence times
- Reagent addition.

Choosing the correct values for these variables will ensure that the best recovery will be obtained for a specified grade.

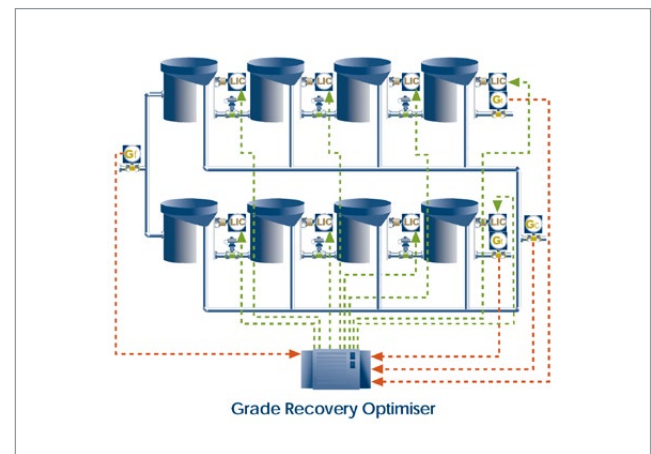
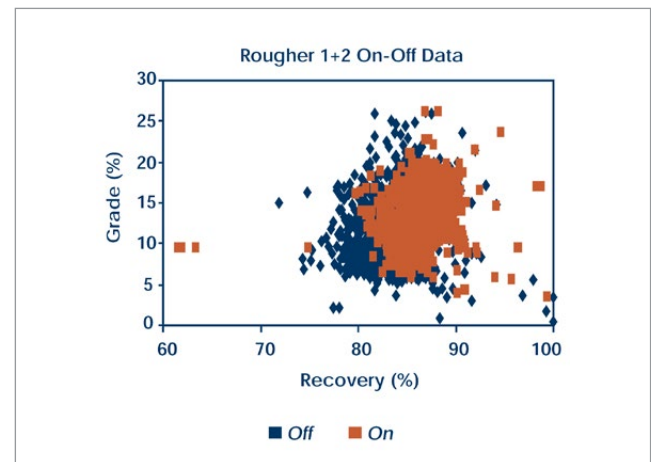
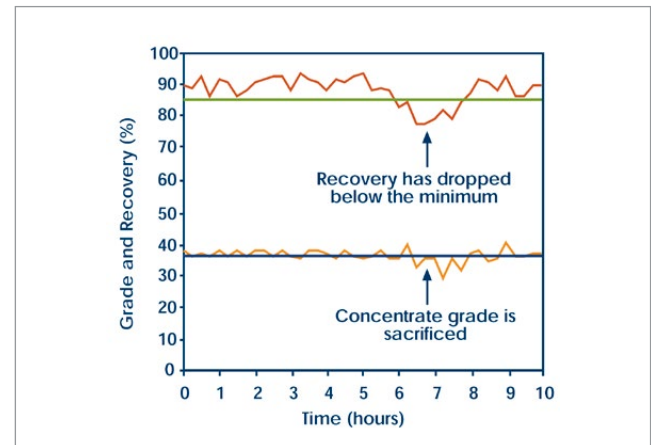
In most cases, the Grade-Recovery Optimiser is configured to prioritise recovery while attempting to ensure a consistent product grade. In the simulated scenario (top graph on the right), at one point the recovery has dropped below the minimum. The Grade-Recovery Optimiser then adjusts the circuit operation to increase the recovery.

As a consequence, the concentrate grade decreases. The graph on the right (actual plant data) illustrates the following benefits of the Grade-Recovery Optimiser:

- Reduction in the variation of the grade (y-axis)
- Increased recovery (x-axis).

Since it is in touch with the entire circuit, it is able to constantly and consistently optimise the full spectrum of variables to ensure peak circuit performance at all times.

The figure to the right shows how the Grade-Recovery Optimiser would be installed on the Rougher section of a typical circuit.



Case study

The graph on the right shows the typical effect of the optimiser on the level setpoints of the circuit. The levels being manipulated are the three lines of four rougher banks each. These banks were self-aspirating, and hence the aeration rate was not available for manipulation.

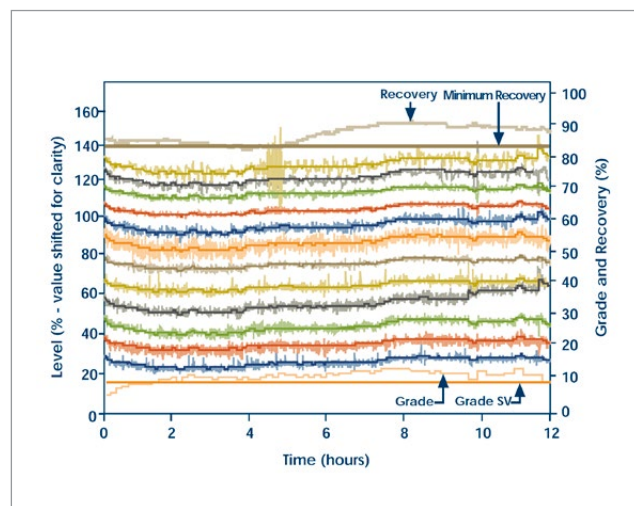
The objectives of the optimiser on this section of the circuit were as follows:

- Control Rougher concentrate grade to setpoint
- Maximise Rougher recovery.

A benefit analysis was conducted on a copper plant using the Grade-Recovery Optimiser. On and Off data were collected over several months, and the difference in performance was assessed.

Statistical techniques were used to verify the results. The values were found to be valid with a 95% statistical confidence.

The table below shows the results of this analysis:



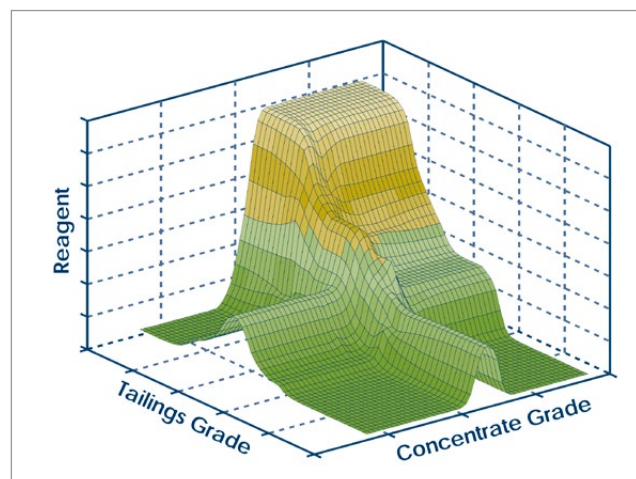
	Normal PID Control (mean)	Grade-Recovery Optimiser (mean)	Difference
Recovery	86.36%	88.35%	1.99% improvement
Feed Grade	1.632%	1.634%	Statistically equal
Concentrate Grade	37.51%	37.32%	Statistically equal
Tailings Grade	0.226%	0.197%	0.029% decrease

Reagent Optimiser

Reagents play an important role in froth flotation. They strongly affect the performance of the circuit and contribute considerably to the circuit operating costs. The selection of the reagent suite is a complex task, with multiple, often counterintuitive, rules and calculations.

The Reagent Optimiser aims to automate this process, to provide consistent round the clock adjustments to the reagent suite tailored to the plant operating conditions.

The figure on the right is a graphical representation of a fuzzy logic calculation that forms part of the Reagent Optimiser. In this case, the plant concentrate and tailings grade readings are used to make decisions regarding adjustments to one of the plant reagents.



Features:

- Incorporates fuzzy logic
- Uses plant feedback
- Nonlinear, multi-input, multi-output controller
- Functions cooperatively with operators and metallurgists
- Customisable for additional calculations and logic
- Detection of, and reaction to, invalid grade measurements
- Automatic adjustment to feed tonnage changes
- Plant-specific switch-on logic
- Complements the FloatStar Grade-Recovery Optimiser.

Benefits:

- Consistent changes to reagents
- Efficient usage of reagents through continuous analysis of circuit requirements, thus decreasing reagent usage
- Maximises recovery by preventing unnecessary losses due to reagent under-dosing.

The Reagent Optimiser can be combined as a comprehensive solution with the Flow and/or Grade-Recovery Optimisers to ensure optimal plant performance.

Performance Monitor

Controllers must not only perform well in the conditions under which they were installed and tuned, but must also be robust through fluctuating plant conditions.

The FloatStar Performance Monitor keeps track of controller performance at all times, and produces useful diagnostic information to analyse when and why controllers are not performing at their peak.

Both plant personnel and control engineers will find this information useful in ensuring that their controllers are always performing well.

Currently the Performance Monitor:

- Provides a comparison of the performance of the flotation circuit when the controller is on and off
- Compares the current performance to a defined "Optimal Performance"
- Can be configured to reject specific invalid operational periods (e.g. very low flows, saturated actuators)
- Determines periods of poor performance
- Provides diagnostic information for determining faults.

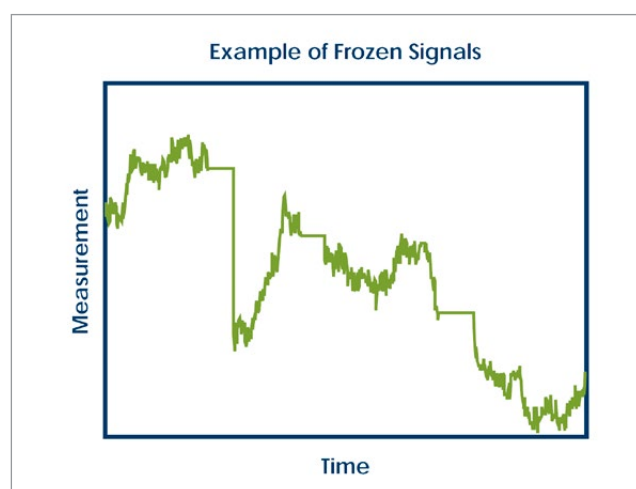
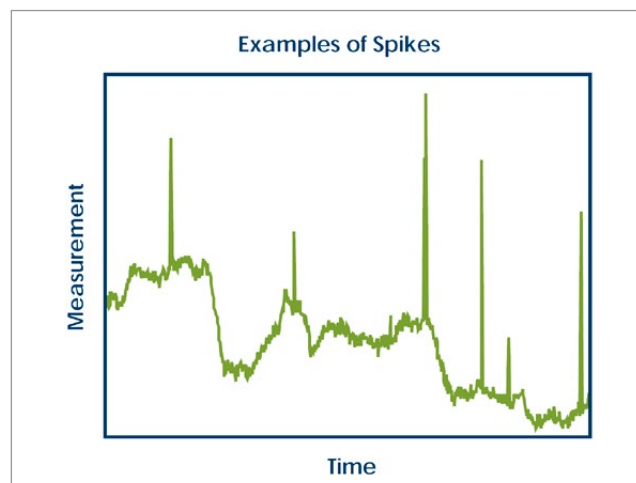
Level Fault Detector

The FloatStar Level Fault Detector is an online module that detects level-related faults in sumps and flotation banks. It provides useful feedback regarding flotation and general level-instrument performance.

The Level Fault Detector has several fault-detection routines, and a general statistics and performance-monitoring package. The fault detection routines include a frozen signal detector, a signal-spike detector and an overflow detector. The statistics module provides information on a moving window of data, including minimum value, maximum value, average, standard deviation and instrument resolution.

A graphical interface also forms part of the fault detector package. This interface has been designed to give the users intuitive feedback regarding faults on the plant, without overloading them with too much information or alarms.

The figures on the right are examples of spiking and frozen signals.



Additional Stabilisation

pH Control

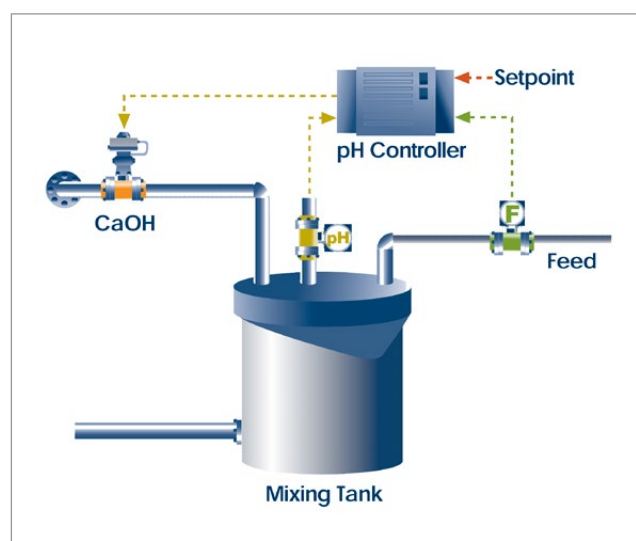
The control of pH is required in a vast number of areas in the mining industry. A key area is in flotation reagent control systems. There are a number of difficulties in controlling pH:

- Non-linearity of the pH curve;
- Silting up of the base (typically CaOH) feed -valve
- Compensating for changing feed conditions.

The FloatStar pH controller is designed to handle all of these control difficulties and consists of:

- An advanced multi-variable algorithm, including feedforward and feedback compensation
- Non-linear compensation
- Fault detection algorithms.

The above techniques have been combined into a pH controller that is simple to set up, and provides robust control in an industrial environment.





Simulators

Dynamic Flotation Simulator

The FloatStar Dynamic Simulator is a tool for modelling flotation circuits. It incorporates a mechanistic model that takes into account the dynamics of both true flotation and particle entrainment.

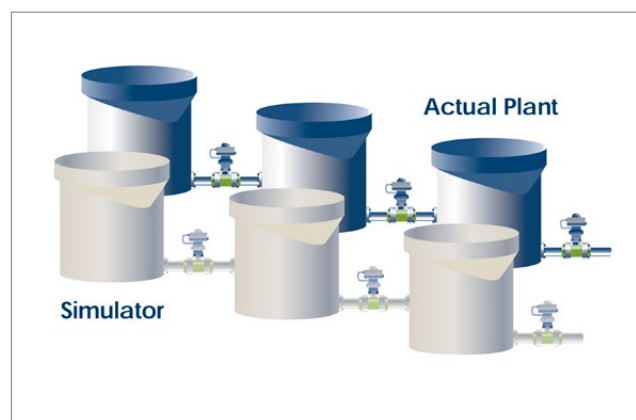
The simulator has two modes of operation: True dynamic mode and steady-state mode. In dynamic mode the simulator mimics an actual plant, with dynamic responses to changes in plant operating conditions. The steady-state mode is more useful for testing different plant designs and configurations.

The dynamic mode allows the user to:

- Change flowrates, valve positions and other dynamic plant properties during run-time
- Predict the process response due to changes in head grade, flowrates, level setpoints and air setpoints
- Prototype control and optimiser systems for an actual plant
- Train operators using SCADA-like frontends.

In the steady-state mode the user can:

- Change steady-state variables such as flotation bank areas and circulating loads
- Trial different plant designs
- Optimise steady-state variables such as residence times.



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