Presented at the 12th Australian Coal Preparation Society Conference

Development of an Online Residual Frothing Propensity Detector

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ABSTRACT

Residual frother is a major problem in coal and minerals preparation plants. This paper describes the development of a new online device that measures the residual frothing propensity of a feed stream. The Residual Frothing Propensity Detector (RFPD) has been developed to be installed on the clarified water system of a processing plant. When there is residual frother in the clarified water the propensity for bubbles to form increases. When residual frother is present it generates froth within the feed sumps which can cause the feed pumps to the dense medium cyclones to cavitate causing the plant to froth out and be shut down.

The RFPD works by maintaining a set of fixed conditions while measuring the airflow and vacuum. The RFPD is then able to measure the propensity for bubbles to form at these set conditions for clean water. The device is then calibrated to the specific frother being used in the coal or minerals processing plant. The changes recorded by the RFPD in the vacuum and airflow are then directly related to the concentration of frother within the feed source. The RFPD is able to then transmit this data to the plants communication system and provide real time information to an operator indicating the concentration of residual frother in the clarified water being monitored. The RFPD is calibrated to frother, however measuring the propensity to form bubbles also takes into account effects caused by salt.

INTRODUCTION

Recovery of fine coal particles (-0.5 mm w/w or finer) in many coal preparation plants is achieved through the use of froth flotation. The flotation process is aided by two chemical reagents commonly known as collectors and frothers. The performance of the flotation cell is heavily dependent on the optimization of both of these reagents. Collector is used to coat the surface of the coal particles to make them more hydrophobic, increasing the coal particles affinity to attach to an air bubble. The frother reagent aids in the formation of air bubbles, strengthening the walls of the air bubble and stabilizing the froth. Both reagents pass out of the flotation cell with the product and also with the tailings stream from the cell. The tails typically then go out to a tailings thickener. The concentrate passes to a dewatering step such as a coal thickener, screen bowl centrifuge or some type of filter.

The water circuit within a fine coal flotation plant is generally not a closed circuit. The tails from the flotation cells go to the tailings thickener. The residual amounts of frother in the tails then overflow from the tails thickener and enter the clarified water circuit of the plant. Water is also recovered in dewatering the concentrate. These sources of reclaimed water have residual amounts of frother in them.

The clarified water is used as make up water throughout the coal preparation plant. This is where the residual amounts of frother cause major problems. The clarified water is used in the dense medium sections of the plant in making up the dense medium. Frother is designed to aid the formation of air bubbles and introducing frother into a high vertical velocity and high shear zone generates froth. This can also lead to instability of the dense medium, as air bubbles in the dense medium affect the readings from the density gauges. Froth causes pumping problems. The froth is sucked into the feed pumps to the dense medium cyclones, causing them to cavitate possibly leading to a plant shutdown.

The fine's flotation section of a coal processing plant is typically 15-20% of the plant's production whereas the dense medium section is 80-85% of the production. To solve the problems caused by residual frother, plants deliberately dose the fines flotation cells much lower than the required frother dose to achieve the maximum yield from the flotation cell, as they have had no way to measure the level of residual frother in the clarified water circuit online or otherwise. This was found to be the case by Lahey and Clarkson (1999) on two coal preparation plants in which they found that both plants were “considered frother constrained”, and consequently sacrificed production yield from their fines flotation by dosing low to avoid frothing problems in other parts of the plant.

The effects of residual frother within a processing plant are well known. There have been projects conducted by the CSIRO to develop laboratory tests to detect the level of residual frother in a process stream. A device was developed by Hart G., (2006), that was able to detect the level of residual frother in clarified water. The device was based on an alcohol breath tester device. The device was developed to detect alcohol based frothers, such as methyl-iso-butyl-carbinol (MIBC). This device was never commercialised. The use of MIBC has dramatically reduced due to OH&S issues related to its volatile nature. Laboratory tests using gas chromatography-mass spectrometry equipment has been done but due to the volitile nature of frothers by the time a test sample can be analysed at a laboratory it may well have partially or totally evaporated, and the results are not real time.

A laboratory test to detect the level of residual frother in a process stream was devloped by Ofori, P.,Hart, G., Vince, A., (2007). This test took a sample of the process stream and placed it into a column. Air was pumped into the column at a known rate and the bed expansion of the sample measured as well as other factors. This device needs to be calibrated to the individual frother being used. This was developed as a laboratory test only.

The performance of a froth flotation cell is directly related to the dose rate of frother to the cell. In a Jameson or Microcel frother should ideally be added at up to 30ppm (v/v) of fresh flotation feed slurry, however no plant can handle such a high dose rate of frother without major residual frothing problems in other sections of the plant, generally most plants operate at 5-15ppm (v/v) Sanders (2007). The process water can also have an effect on the flotation cell performance, as most operations use reclaimed water that has high salt concentrations which also have an effect on the water chemistry and flotation cell performance.

The RFPD allows plants to monitor online the residual frother level in the clarified water circuit. This will let operators increase the level of frother being dosed into flotation cells as downstream effects of residual frother will able to be monitored and controlled. The increase in frother dose rates will increase the yields from the fines flotation circuit.

THEORY

Froth flotation is used to recover coal particles typically less than 0.5 mm in size. The surface properties of a coal particle are hydrophobic in slurry, while the surface properties of the shale and clay material present in the slurry are hydrophilic. When an air bubble is introduced into the slurry the hydrophobic coal particle will attach itself to the air bubble. The coal particle attached to the air bubble will then have a relative density less than the suspension and rise to the surface from where it can be removed.

The RFPD device (Figures 1 and 2) uses this ability of the frother to form bubbles to measure the concentration of the frother in the clarified water circuit being monitored. The device maintains a set of fixed conditions and the changes in these are recorded by the device.

The device measures the changes in pressure within a column of water. A column of water will have a static vacuum pressure according to equation (1)

$$\Delta P = \rho \times g \times H \qquad (1)$$

Where: ΔP = pressure (-kPa)
ρ = water density (t/m^3)
g = acceleration due to gravity (m/s^2)
h = height (m)

The maximum vacuum pressure in the bubble column is measured and recorded. This maximum vacuum must be measured when the column is full and there is a constant head pressure. The head pressure is maintained by using a constantly overflowing head tank. It is of critical importance that there is no air in the column of water when the maximum vacuum pressure is recorded, as this will change the density of the liquid in the column giving a false reading. Using the head tank also acts as a de-aeration vessel.

Once the maximum vacuum has been determined, it is altered by introducing air into the column through the mixing head. The mixing head has an internal jet nozzle that draws air into the column. The vacuum pressure is decreased in the column as there is an air and water mix now in the column, so the density of the liquid has changed. This is shown in equation (2)

$$\rho_{total} = \frac{m_w + m_a}{V_{total}} \qquad (2)$$

where ρ_{total} is the total density of the fluid in the bubble column, m_w is the mass of water in the bubble column, m_a is the mass of air in the column and V_{total} is the total volume inside the bubble column

Equation (2) can then be expressed as

$$\rho_{total} = \frac{\rho_w V_w + \rho_a V_a}{V_{total}} \qquad (3)$$

Where ρ_w is the density of the water in the bubble column, v_w is the volume of water in the bubble column, ρ_a is the density of air in the bubble column and v_a is the volume of air in the bubble column. From this equation (1) can now be expressed as

$$\Delta P = \left(\frac{\rho_w V_w + \rho_a V_a}{V_{total}}\right) \times g \times H \qquad (4)$$

The vacuum pressure is a combination of the static vacuum pressure and the dynamic vacuum pressure. The dynamic vacuum pressure in this case is kept as a constant by maintaining a constant head pressure to the RFPD from the overflow head tank.

The maximum vacuum inside the bubble column is measured by the control device. This is then altered by making the set point vacuum less than the maximum by -2 (kPa). The airflow is recorded and this is then set as the zero point for the device. The control device then maintains this set point. No frother can be present in the water when setting this point and also the conductivity of the water needs to be recorded. It is best done with distilled water.

Frother decreases the size of air bubbles and also generates more air bubbles so, when it enters the column of water the vacuum pressure is decreased in the column of water as the density of the fluid changes. The control device is able to then measure this change in vacuum pressure directly and then is able to compensate for it by increasing the airflow into the column of water to get back to the set point.

The control device is then able to measure and record theses changes in airflow. A calibration needs to be done for the device for each individual frother as they have different chemical properties. Once a calibration has been performed for the individual frother, a calibration equation is developed and entered into the device so that the changes in airflow can be directly related to the changes in frother concentration online, giving real time information to a plant operator.

The calibration process involves making up known concentrations of the frother and running them through the RFPD and recording the airflow for that concentration of frother.

Even though the device is calibrated to the individual frother being used, it measures the propensity of bubbles to form so it will take into account increases in the salt concentration which has an effect on the frothing ability of a water stream and also fine clay particles that also influence the propensity to form bubbles.

ANALYSIS

The initial apparatus developed for the project used manual vacuum gauges to record the vacuum and also a pressure gauge to measure and record the feed pressure. This is shown in figure 1 below. The airflow rate was recorded using manually adjusted air rotameters. Using this initial apparatus showed changes needed to be made to the setup. One essential change was to use a constant overflowing head tank to provide constant head pressure to the unit. Relying on a gate valve to regulate the pressure was not accurate enough. Another change to the initial apparatus was centered on the length of the bubble column itself. The initial test work was done using a 1m column and then increased to 2 m to give a higher vacuum and larger change in airflow as the frother concentration was increased. The column length was increased to 3 m, with the thinking again being an increase in the changes in airflow giving a more definitive and accurate readings. This did increase the separation in the readings but lead to uncontrolled air being drawn into the bubble column due to sealing problems.

The device was then trialed at Mount Thorley Warkworth North CHPP in a concurrent trial with a laboratory technique developed by the CSIRO (Ofori et al, 2007) to measure the frother concentration in a feed source. The RFPD performed well giving a reading of 2.4 ppm (v/v) of frother in the clarified water. The results from the CSIRO lab method gave a result of 2.5 ppm (v/v) of frother in the clarified water. This showed that the RFPD was a giving comparable results to the CSIRO lab method even though it relied on manual reading and adjustment which is always open to error due to incorrect reading of the measurement devices.

Figure 1.
Manual test apparatus

The control of the device was then upgraded to a fully automated control device that is able to measure and record the vacuum pressure and change the air flow and maintain the set point by opening and closing an automated control valve. The control device is also able to measure the airflow, and once a calibration equation has been developed for the frother, it can be entered into the device. The device can then be linked to a plants communication system and the residual frother concentration in the clarified water monitored online. A Schematic of the device is shown in figure 2, this gives an outline of the basic operation and setup of the device.

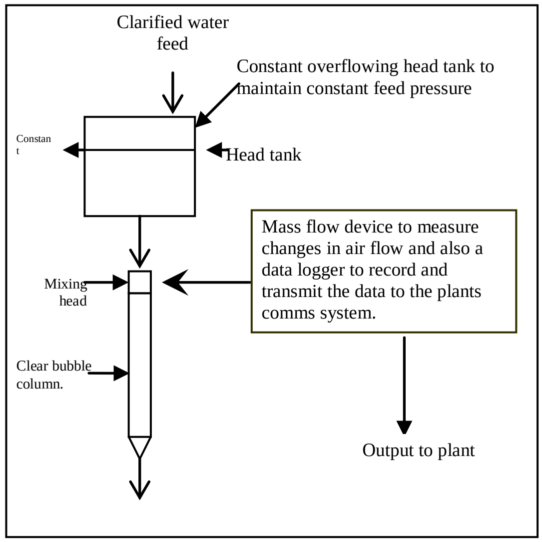

Figure 2.
Schematic of RFPD.

SAMPLING

The calibration of the device was done in laboratory facilities using distilled water and solutions made up to an accurate concentration. The device was trialled onsite at two CHPP's using the plants clarified water as the feed source.

RESULTS

The first stage in the development of the device was to prove the concept would work and that the changes in frother concentration could be measured. The instrument used manual pressure gauges, vacuum gauges and air rotameters at this first stage of the development.

The first stages proved successful as shown in figure 3 below. The accuracy of these results however proved inconclusive and the device underwent several design changes with various degrees of success. The main aim however of the first stage was successful in that the device was able to detect and measure the changes in frother concentration within the bubble column to a certain degree.

Sample No.	Frother ppm (v/v)	Feed Pressure (kPa)	Vacuum Pressure (-kPa)	Air Intake Rate (L/min)
1	0	50	14.25	0
2	0.5	50	13.5	3
3	1	50	13.5	3
4	2	50	13.5	3.25
5	3	50	13.5	3.5
6	4	50	13.5	3.75
7	5	50	13.5	3.75
8	10	50	13.5	3.75
9	20	50	13.5	4.5
10	30	50	13.5	5

Figure 3.
Initial test results

Figure 4 shows data collected using the manual operating system to adjust the air flow to maintain the set point. The data was then analysed and using a log-log plot to produce a straight line relationship between frother concentrations with increases in airflow was produced.

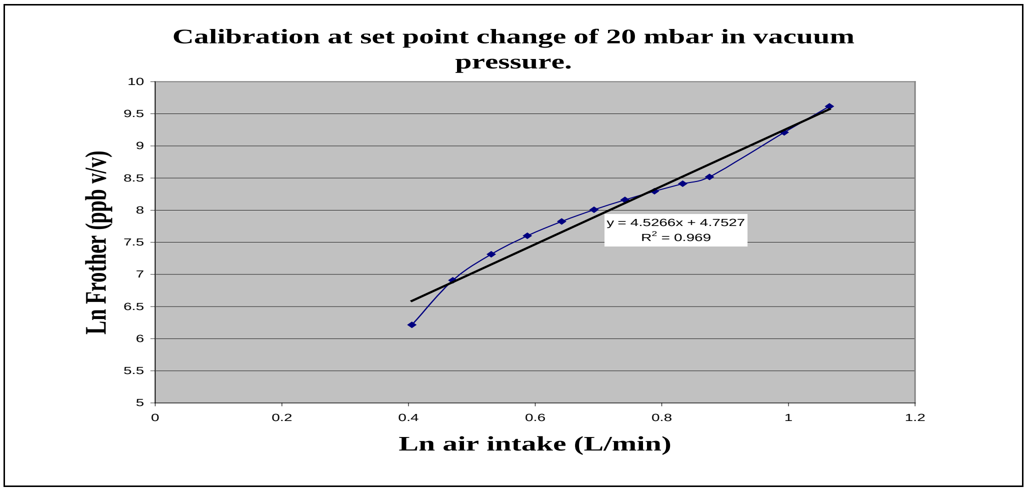

Figure 4.
Manual calibration data for RFPD

The next stage of the development was to automate the measurement and air control devices. A solution was found in a control device that can monitor changes in the vacuum pressure within the bubble column and is able to maintain a pressure set point by increasing the airflow by opening and closing an automated control valve. The device is then also able to measure the airflow into the bubble column. The control device once installed was then used to produce a calibration chart for the RFPD shown in Figure 5. From this chart it is clear to see the relationship in airflow to frother concentration that is as the frother concentration increases in the bubble column the amount of air needed to be let into the bubble column by the control device increases.

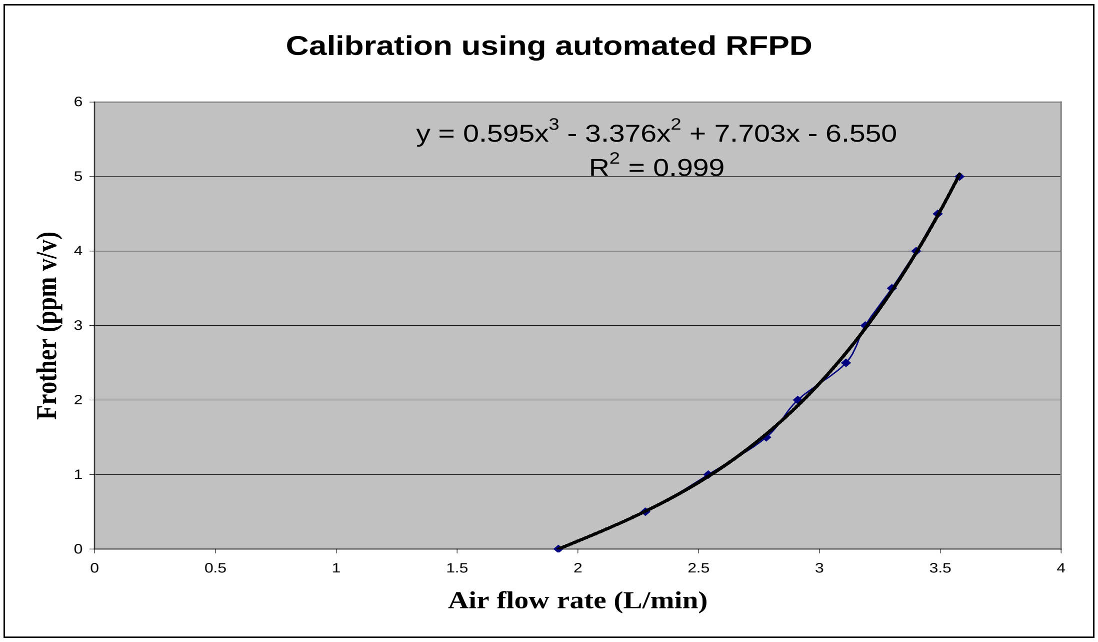

Figure 5.
Calibration chart produced using automated control device.

Error Analysis					
	RFPD	Actual	Error	Error	
Air rate	Frother	Frother	Frother	(abs)	(abs)
	Reading				
(L/min)	(ppm v/v)	(ppm v/v)	(ppm v/v)	(ppm v/v)	(%)
2.28	0.51	0.5	-0.01	0.007	1.4
2.54	0.97	1	0.03	0.025	2.5
2.78	1.54	1.5	-0.04	0.043	2.9
2.91	1.92	2	0.08	0.076	3.8
3.11	2.63	2.5	-0.13	0.133	5.3
3.19	2.96	3	0.04	0.037	1.2
3.3	3.47	3.5	0.03	0.034	1.0
3.4	3.98	4	0.02	0.024	0.6
3.49	4.48	4.5	0.02	0.019	0.4
3.58	5.03	5	-0.03	0.032	0.6

Figure 6.
Error analysis performed from calibration equation

Figure 6 shows an error analysis that was performed on the calibration equation developed for the frother being used for the onsite trial of the RFPD. The error analysis showed that the device operated at a maximum error of 5.3% of the actual reading.

The RFPD was installed onsite at a CHPP. A calibration procedure was done for the specific frother being used at the CHPP as it was different to the laboratory trial work which used MIBC. The frother being used for the calibration was firstly emulsified. A calibration equation was produced from this work and then entered into the RFPD data logger. The data logger was then able to give an output of frother concentration in ppm (v/v). In Figure 7 below the onsite trial data is shown. At the time the RFPD was not connected to the plant's communication system, the data was collected from the unit and analysed offsite. The data collected by the unit clearly highlights what can happen when the residual frother concentration in the clarified water system is too high, which in this case lead to a plant shutdown. The plant was washing a low ash feed that floated readily so the dose rate to the flotation cells was low. The feed to the plant changed to a higher ash coal that did not readily float so the dosage rate of frother was increased. This led to an increase in the amount of frother exiting the flotation cells with the tails going to the tailings thickener where it entered the clarified water circuit.

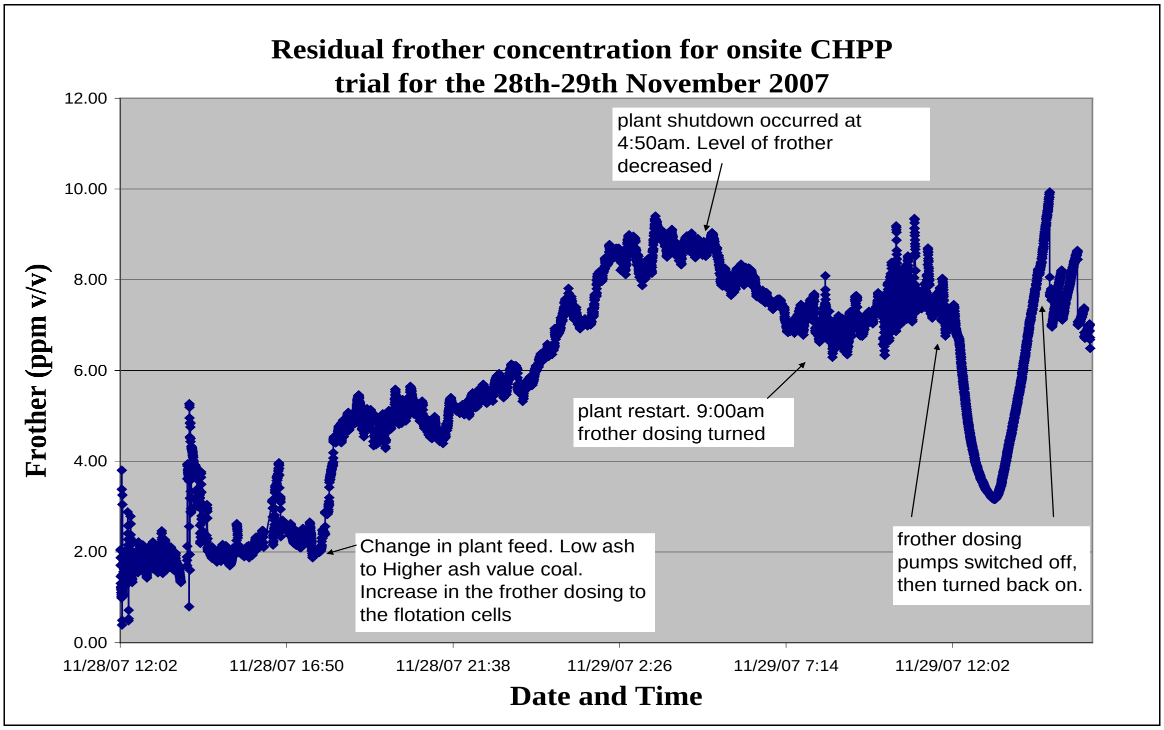

Figure 7.
Onsite trial run data from RFPD

Figure 8 shows data collected from the same CHPP onsite trial where the highest level of residual frother detected in the clarified water system over a 12 hour period was just over 1.4 ppm (v/v). The plant was washing a low ash feed that was readily floatable so the frother dose to the flotation cells was relatively low. Also when the flotation cell is working well the tendency is for the majority of the frother to exit the flotation cell with the product, rather than exiting the cell with the tails.

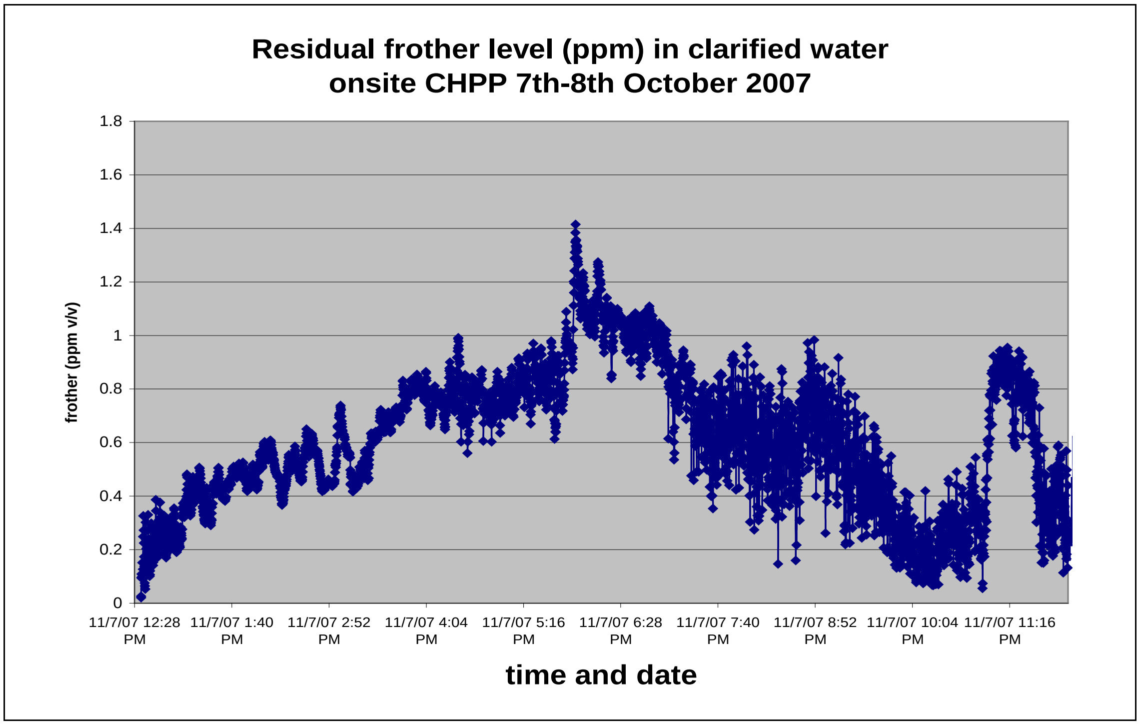

Figure 8.
Frother concentration (ppm v/v) onsite trial CHPP.

The onsite trial was conducted over a 4 week period. During this time period the unit tracked and recorded changes in the concentration of residual frother in the clarified water circuit. Information from the unit was downloaded and analysed every 2 days and the portable power supply replaced. In figure 9 the commercial RFPD is shown.

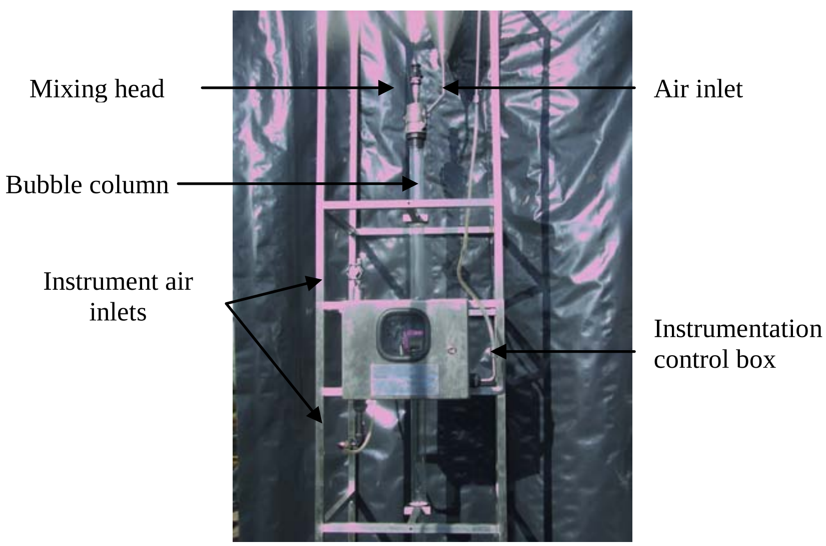

Figure 9.
Commercial RFPD unit.

DISCUSSION

The RFPD has been developed to be an online device that provides real time data to plant operators of the level of residual frother in the clarified water within the CHPP. The device was firstly intended to be installed on the tails coming from the froth flotation section of the plant, so the level of frother going out in the tails could be directly monitored. This however will not give any real indication of the level of residual frother in the clarified water circuit. For example the level of residual frother in the flotation tails is say 8 ppm (v/v) going to the tails thickener. The clarified water used by the plant is typically a mix of raw water and the thickener overflow so there will be a dilution factor on the residual frother level entering the plants clarified water circuit. There will be an amount of frother that will go out of the thickener in the thickener underflow as well. So by monitoring the level of residual frother exiting in the tails from the flotation cells, it does not give any real indication of the level of residual frother in the plants clarified water, as no other dilution factors are accounted for.

The yield from froth flotation cells is heavily dependent on the amount of frother being dosed into the flotation cells. The higher the frother dose the higher the yields from the flotation cells. This is not however the industry norm. The typical scenario scene where froth flotation cells are used, is to dose the flotation cells at so called safe levels such that the cells are yielding a product, but the level of residual frother in the clarified water being used throughout the rest of the plant, is not high enough to cause any major problems in the dense medium sections of the CHPP. Ultimately this leads to loss of production from the CHPP as the fine's flotation circuit is sacrificed to keep the rest of the plant from 'frothing out". This was shown in the commissioning of a pilot scale turbo column flotation cell by Engelbrecht, Terblanche, Bosman, J.B. (2000) where to avoid frothing problems in sumps and tanks the frother dose to the flotation cell was lowered.

The simple truth is that there has been no way to measure the level of residual frother in the clarified water. There have been other devices developed such as alcohol based detectors Hart (2006), which was predominately developed to detect MIBC. There has been a move by the industry away from MIBC due to its explosive nature, storage and OH&S issues. The alcohol type units are limited in that they cannot detect other factors that can influence the frothing propensity of a feed stream, such as the salt concentration, which if high enough can cause froth to form and also very fine particles in the clarified water that also affect the frothing propensity of the clarified water. The RFPD is calibrated to the specific frother but as it determines the frothing propensity of a process stream, the other factors that influence the frothing propensity of the process water can be accounted for.

The ability for an operator to have accurate data as to the level of residual frother in the clarified water within the plant leads to greater control and also the ability to push the flotation cells to the optimal dosing of frother, rather than playing it safe and dosing low to avoid causing problems elsewhere in the plant. The other advantage is that froth suppression systems can be inbuilt into the plants system. There are several ways to do this:

1. Link the RFPD output to the frother dosing pumps. When the level gets to high it automatically lowers the dose rate to the flotation cells.
2. Link a froth suppression system to the RFPD such as a diesel dosing pump that pumps emulsified diesel that will essentially kill the froth.
3. The use of activated carbon to remove the frother through adsorption.

CONCLUSIONS

The RFPD is an online measurement device that can accurately measure the propensity for residual frother in the clarified water circuit of a process plant to form bubbles. This is then used to determine the concentration of the frother in the clarified water once the device is calibrated to the individual frother. The device is not limited by the type of frother being used. The RFPD is also able to take into account other factors that influence the frothing ability of the clarified water such as salts and fine particles that tend to stabilize froth. The benefits of the device are real time data on the level of residual frother in the clarified water. This allows the dose rate to the froth flotation cells to be increased, increasing the yield from the flotation cells, while being able to control and minimise affects caused by residual frother in the other sections of the plant.

The RFPD has now finished its development stages and is being commercialized and installed as a solution to the monitoring and control of residual frother levels in CHPP's and other industries where extraneous froth formation is a problem.

REFERENCES

Engelbrecht, J.A., Terblanche, A.N., Bosman, J.B. (2000), "Fine Coal Beneficiation Plant at Robena L.L.C in the United States of America" in Proceedings of the Eighth Australian Coal Preparation Conference, Paper D2 pp159-174

Hart G., (2006), Frother Measurement and Control, Final Report, ACARP project C13056

Lahey, A., Clarkson, C., C Clarkson & Associates Pty Ltd (1999), "Development of Automatic Control Techniques for New Flotation Technologies".

Ofori, P. Hart, G., Vince, A., (2007), "Extraneous Frothing Minimisation and Control", Final report, ACARP PROJECT C15050

Sanders, G. J. (2007), The Principles of Coal Preparation, Australian Coal Preparation society, Newcastle, pp316-346

ACKNOWLEDGEMENTS

The authors of this report would like to thank the following for their assistance throughout this project.

- TUNRA Clean Coal, for the use of laboratory facilities for the development stage
- Glen Hart and Philip Ofori from the CSIRO Energy Technology for their assistance and onsite trial test work
- Tony James CHPP Manager Stratford Coal for allowing the onsite trial work to be carried out
- Tim Walker Electrical Maintenance Supervisor Stratford Coal CHPP
- Paul Revell Senior Process Engineer and Graham Nash Process Engineer from MTW CHPP north for allowing the onsite test work and development
- Kyle McLennan for assisting in the development of the RFPD
- Geoff Curnow for his continuing instrumentation expertise
- Philip Butler Instrumentation Engineer MTW CHPP north

This Residual frothing propensity detector device and concepts behind it have been patented by TUNRA Clean Coal

PROV APP No: 2006903676
PCT APP No: 2007000903