On-line Moisture Determination of Ore Concentrates

‘Review of Traditional Methods and Introduction of a Novel Solution’

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Abstract

The manual moisture determination methods employed today by mineral processing plants falls short in providing timely information required for automation control. The costs associated with transporting and handling concentrates still represent a major portion of the overall treatment price. When considering the cash flow of a mining operation, that is governed by both the smelter contract, with moisture penalties and the quantity and quality of the concentrates shipped, an efficient method of on-line moisture content would be a welcome tool.

A novel on-line determination system for ore concentrate moisture content would replace the normally tedious classic manual procedure. Since the introduction of microelectronic-based control systems, operators have strived to reduce the treatment costs to the minimum therefore a representative and timely determination of on-line moisture content becomes vital for control set points and timely feedback. Reliable sensors have long been on the "wish list" of mineral processors since the problem has always been that you can only control what you can measure. Today, the task of moisture determination is still done in the classical technique of loss in weight by uncontrolled procedures. These same methods were introduced in the earliest base metal concentrators. Generally, it is acceptable to have ore concentrate moisture content vary within a range of 7 to 9%. Many times, delays in manually achieving reliable feedback on the moisture content results in the moisture varying from 5 to 12% before corrective actions can be made.

This paper first reviews the traditional and widely available methods for determining moisture content in granular materials by applying physical principals and properties to measure moisture content. All methods are in some form affected when employed on mineral ore concentrates. This paper describes a unique and promising on-line moisture sensor in two mineral processing applications, which not only automates the tedious tasks but also results in reliable moisture feedback that can be used in the optimization of the de-watering process equipment such as pressure or vacuum filters and fuel-fired driers. Finally, two measurement applications will be presented to indicate the usefulness and to summarize the measurement requirements for the proposed method of employing drag force and mechanical properties of the material itself to determine the moisture content.

Introduction

Commercial sensors to measure particulate moisture content have been available for laboratory use for many years. Although it has been approximately 40 years that on-line methods have become common in industrial applications, they have not become the norm in mineral processing plants for a number of physical property reasons. These physical principles or properties of the material under measurement categorize these measurement methods. They include electrical conductivity, dielectric properties, microwave absorption and radio frequency transmission. Each is affected by the electrical properties of the conductive ore such as copper, lead and nickel concentrates or the contained water and therefore cannot be reliably employed. The errors with conductivity-based measurements also make them difficult to employ since they depend on the level of dissolved water impurities and the composition levels in the concentrate. This means as the pH or water quality changes in the concentrate, new calibration is required to correct drifting of the results. The use of radio frequency transmission has been tested on zinc concentrates but inter-elemental effects such as the amount of iron present make calibration too complex and unreliable.

Sensors using infra-red reflectance technique are also common in industrial use. This technique involves a surface determination, which must be representative of the layers of the bulk material being analyzed. The measurement is also affected by the concentrate's optical absorption at wavelengths used to characterize the water content. The optical path from the light source to the material surface and from the material surface to the infra-red detector must be free of highly infra-red absorbing materials such as water vapor or mirror-like reflections which make this technique unusable.

Neutron activation principles have also been in use for difficult applications where moisture determination is desired. This method determines the hydrogen content in the material from which moisture content is inferred. The measurement is based on the deceleration of fast neutrons in conjunction with the absorption of gamma radiation to establish density. The systems are generally bulky and heavy due to the required lead shielding used to diffuse the radiation emitted. These systems are also relatively complex compared to other systems described. A summary of many commercially available moisture measurement technologies, which can be used for granular materials, is given in Table 4 at the end of this paper. From the table, it is evident that more work is required to find a reliable on-line sensor for moisture content in mineral concentrates.

The conclusions drawn by the inventors, after reviewing the many available technologies, lead them to investigate the development of a sensor not affected by the electrical and/or optical properties of either the particulate material or associated moisture. The mechanical properties of powders, such as cohesiveness and resistance to flow, are highly dependent on the moisture content, and a simple means to measure the former can be of value in estimating the latter (Carr-Brion, K. 1986). The sensor would use the mechanical properties of the particles such as drag forces to equate the moisture content of the bulk material.

Physical Principles of Water

When detecting the presence of water, it is important to understand that water is in a wide variety of states that can be described by two categories, bound water and surface water.

The Academic Press Dictionary of Science and Technology defines water by two categories. The first is surface water, "all bodies of fresh water, salt water, ice, and snow on the earth's surface. Surface water is the state most commonly associated with water in which it sits with the host material throughout its volume. It also covers liquids, which form creams, oils, emulsions and colloids."

The second category is the chemically bound water or just bound water and is defined as, "molecules of water held tightly by chemical groups in a larger molecule; proteins tend to hold water in this way. Bound water may not freeze until as low as -40° C."

The degree of hydrogen bonding changes with different forms of water and is affected by the chemical environment and the temperature. The same can be said for the dielectric constant as described by the property of a material that determines how much electrostatic energy can be stored per unit volume of the material when voltage is applied. The dielectric constant of water changes with its form and the change from one form to another varies with the frequency of measurement. Measuring the capacitance of materials containing water at various frequencies gives an indication of the amounts and the relative forms of moisture present. The dielectric constant plotted against frequency shows up to three plateau regions and indicates the state of the water; i.e., surface or bound water. Instruments have been developed using the dielectric principle to measure the capacitance of materials at both fixed and varying frequencies but as yet none are completely reliable in ore concentrates. More details on the dielectric principle are given in Table 4 under capacitance measuring technique at the end of this paper.

The water that we are concerned with in mineral concentrates is surface water, so the complex forms of bound water are not referred to in this paper. In other industries such as food products and biotechnology, it is important to know not only how much moisture is present, but also in what form the moisture exists (Carr-Brion, K. 1986).

Sampling Considerations for the Calibration of On-Line Moisture Sensors

The user of on-line moisture sensors must follow good sampling practices when collecting samples for equipment calibration and performance verification. The collection of a number of samples representing the process material must come from the same conveyor belt or process point where the moisture sensor is installed. The samples are analysed by laboratory method for moisture content and then compared with the sensor output at the time the sample was taken.

To achieve the desired instrument performance, the following sampling factors must be followed:

- Any grab sample used for calibration of an on-line instrument must represent the bulk of the granular medium especially in all particle size fractions.
- Representative grab samples from a conveyor belt are best gathered when the material is in free fall at the transfer point of a conveyor belt.
- For irregular material profiles, a material guide or plough can be useful to ensure mixing of all particle size fractions.
- An adequate number of samples must be taken to expose any scatter in the results due to random sampling and analytical errors.
- Samples are adequate enough in water content range to clearly delineate the calibration graph.

Physical Principles of Granular Materials

The Academic Press Dictionary of Science and Technology’s definition for cohesiveness is, “a property of loose, fine-grained sediments whereby the particles stick together as a result of surface forces.”

A classic example of how mineral processing operators have functioned without an on-line moisture instrument is the practice of taking a handful of concentrate and trying to form a ball. Taking this one step further, another example is a simple method of the determination of moisture in sand. Here the measurement for the presence of moisture can be correlated to the ability of a sand bed to pass across slots of varying widths. Both of these methods, although a little primitive, measure the powder's cohesiveness or resistance to flow, which are highly dependent on the moisture content. The mechanical technique of moisture determination and the experimental work presented in this paper, began with an investigation of moisture measurement techniques currently available (Rosenblum 1995-96).

The new technique was further confirmed in parallel work completed by Peter Schiffer and Albert-László Barabasi, of the University of Notre Dame, Indiana. The main purpose of their first experiment was to study the resistance of a solid object moving slowly through a granular medium. They then went on to further their knowledge and to develop the relationship to determine and measure the drag force (F_d).

The work by the Notre Dame team is important in explaining the Noranda Technology Centre working apparatus method for determining moisture since a similar apparatus was used. In the paper, "Slow Drag in a Granular Medium", the granular medium was glass spheres of varying diameters. The measurement sensor was a load cell, which gave a signal based on the force applied by the spheres moving against a rod connected to the load cell. The test was conducted by extending the rod into a cylinder holding the spheres. After numerous measurements, under different conditions, the experiment found that the drag force could be determined by the relationship of:

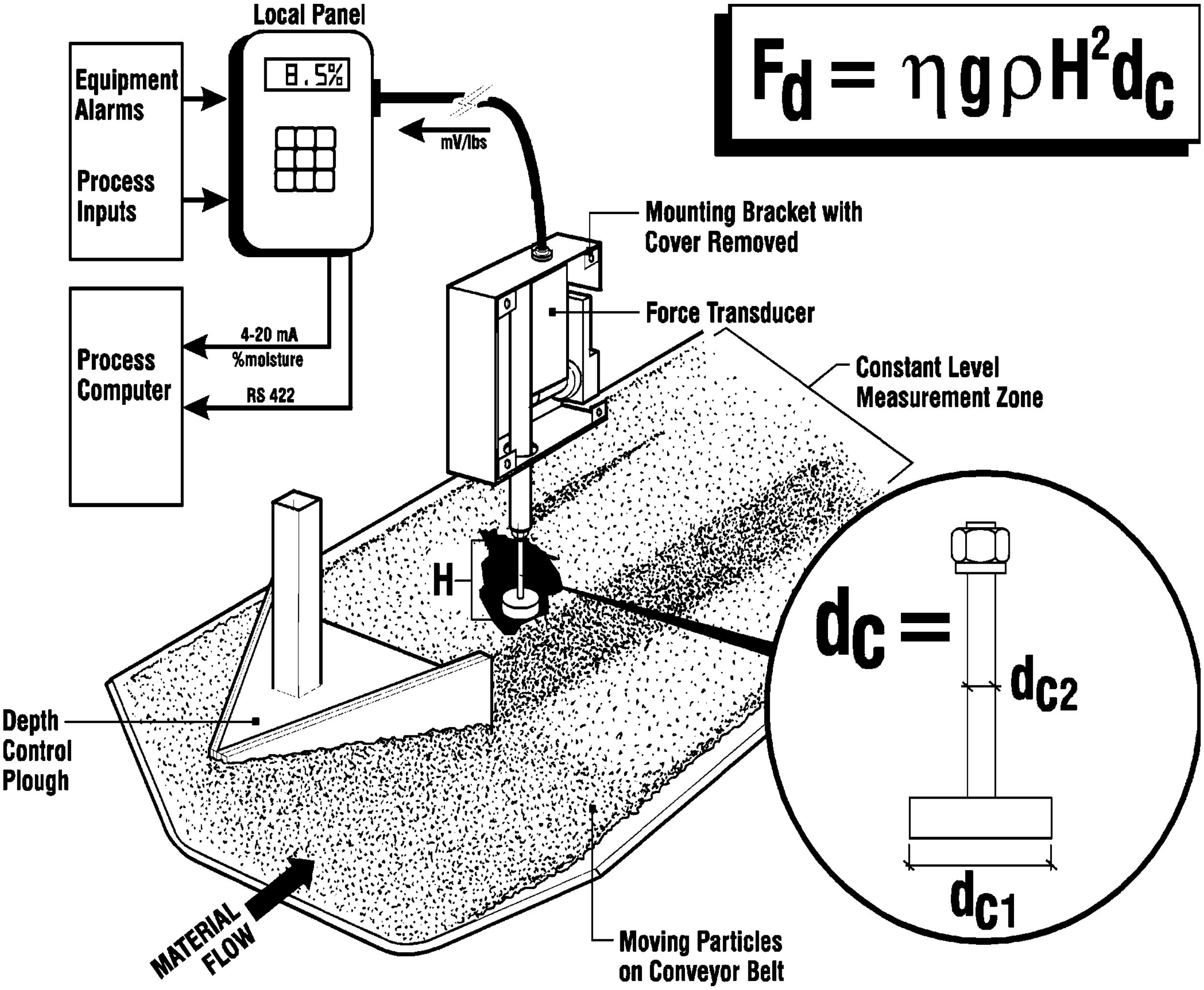
$$\boxed{F_d = \eta\, g\, \rho\, H^2\, d_c}$$

Where: η = characterizes the grain properties (such as surface friction, packing force, cohesiveness etc.)
g = gravitational factor
ρ = the density of the granular medium
H= depth the rod is into the granular medium
d_c= diameter of the rod

This relationship provides the equivalent of a granular Stokes Law for an object moving through a granular medium. The parameter η (the Greek letter eta) is similar to the coefficient of viscosity found in Strokes' law for the force of friction on a fluid flowing through a cylindrical pipe. Figure 1 illustrates an artist's conceptual sketch of the measurement principle for drag force (F_d*)* of granular material on a conveyor belt.

The research work to develop a better understanding of the relationship between drag force of granular particles and moisture content is continuing. Other granular materials are now under test, such as sand, which confirm the relationship is valid, although the influence of the depth the rod is buried into the material (H), is stronger in sand than found in glass spheres used in the first experiment. (P.Schiffer 2000).

Figure 1: Drag Force Measurement Principle in Granular Medium



The drag force principle is dependent on continuous mechanical properties such as resistance to flow associated with each particular granular material. As observed by experimentation, one major distinguishing feature of wet granular media is the phenomenon of clumping (Barabási, Réka and Schiffer 1998). This same phenomenon is easily observed at the beach when making sand castles, as clumps are formed when water is added to sand, which allows the construction of structures normally unstable in dry sand. Similarly, clumping can be equated to the classic example introduced previously where mineral processing operators grab a handful of concentrate and are able to guess the moisture level. Figure 1 also indicates that, with the drag force principle, the only measurement parameters which must be controlled for a true determination of moisture content is the bulk thickness of material against the sensor's rod and disk.

Case Studies of Moisture Measurement on Continuous and Intermittent Load Ore Concentrate Belts

The first application was completed in 1997 at Brunswick Mining and Smelting on Zinc concentrate with a continuous load belt. Table 1 illustrates the material parameters for the measurement with the working prototype tested on Brunswick Zn Concentrate.

Material	Zn Concentrate
Normal moisture range	5-9 %
Flow rate range	30-40 t/hr continuous
Particle Size	90 % - 37 microns (400 mesh)
Speed of belt	1.67 ft/sec

Table 1: Zinc Concentrate Continuous Load Measurement Parameters

At Brunswick, the prototype equipment was installed at an accessible location on the concentrate belt. To avoid any misreading, the stainless steel disk of the sensor was buried to a constant depth within the concentrate flow. A calibration model using linear regression was determined using the sensor signal and laboratory moisture results from grab samples taken from the same point on the belt. The calibration model was then verified by taking samples every 15 minutes and comparing the laboratory moisture content against sensor live measurements. The verification procedure confirmed the sensor was giving acceptable results. The tracking plot, Figure 2, of the sensor moisture measurement shows only slight differences between the laboratory analysis of the check samples taken every 15 minutes.

Observations of the Test Measurement on a Continuous Load of Zn Concentrate

- Bulk layer thickness must remain consistent in front of the sensor transducer or signal varies.
- The affect on the signal due to layer thickness can be slightly compensated by the selected size and shape of rod and disk connected to the transducer.
- When the measurement went out of range, the moisture calculation stopped at the peak value for the transducer. The saturated point of the transducer is indicated at 17:31 to 17:56 on Figure 2. During this time, the moisture reading was very high at 11 %, which was the maximum value of the selected force transducer.
- The measured values displayed on the process computer were very useful during the disturbance period.
- Good correlation of the signal from the force transducer to moisture content of Zn concentrate was achieved and measurement verification was possible, see Figure 3.

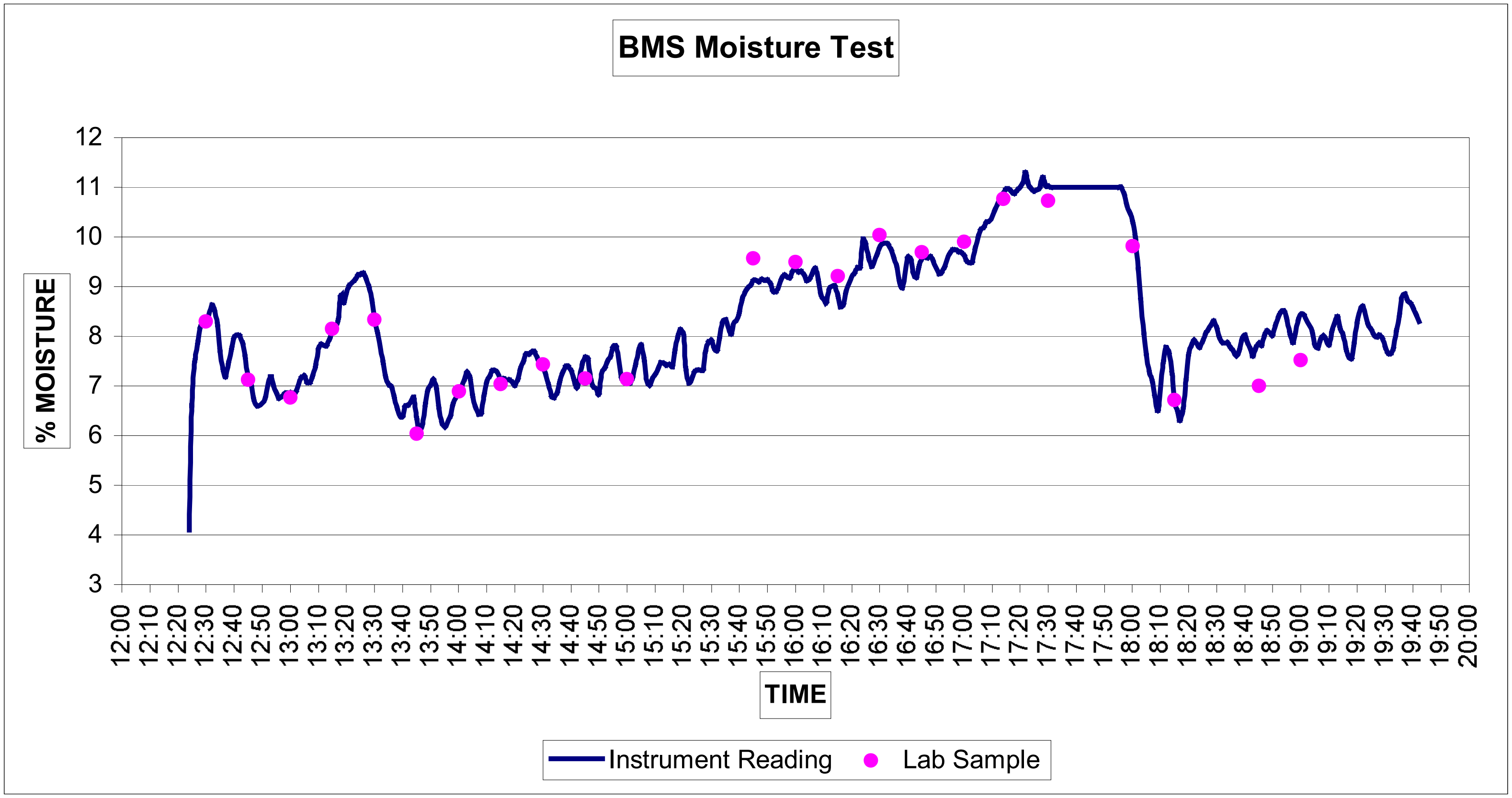


Figure 2: Brunswick Mining & Smelting Moisture Test

Figure 2 illustrates that with a continuous load belt within the normal operating range reliable results were achieved. For the time between 17:20 to 17:50 the flat output was the time a disturbance in the process caused the force transducer to go to maximum output.

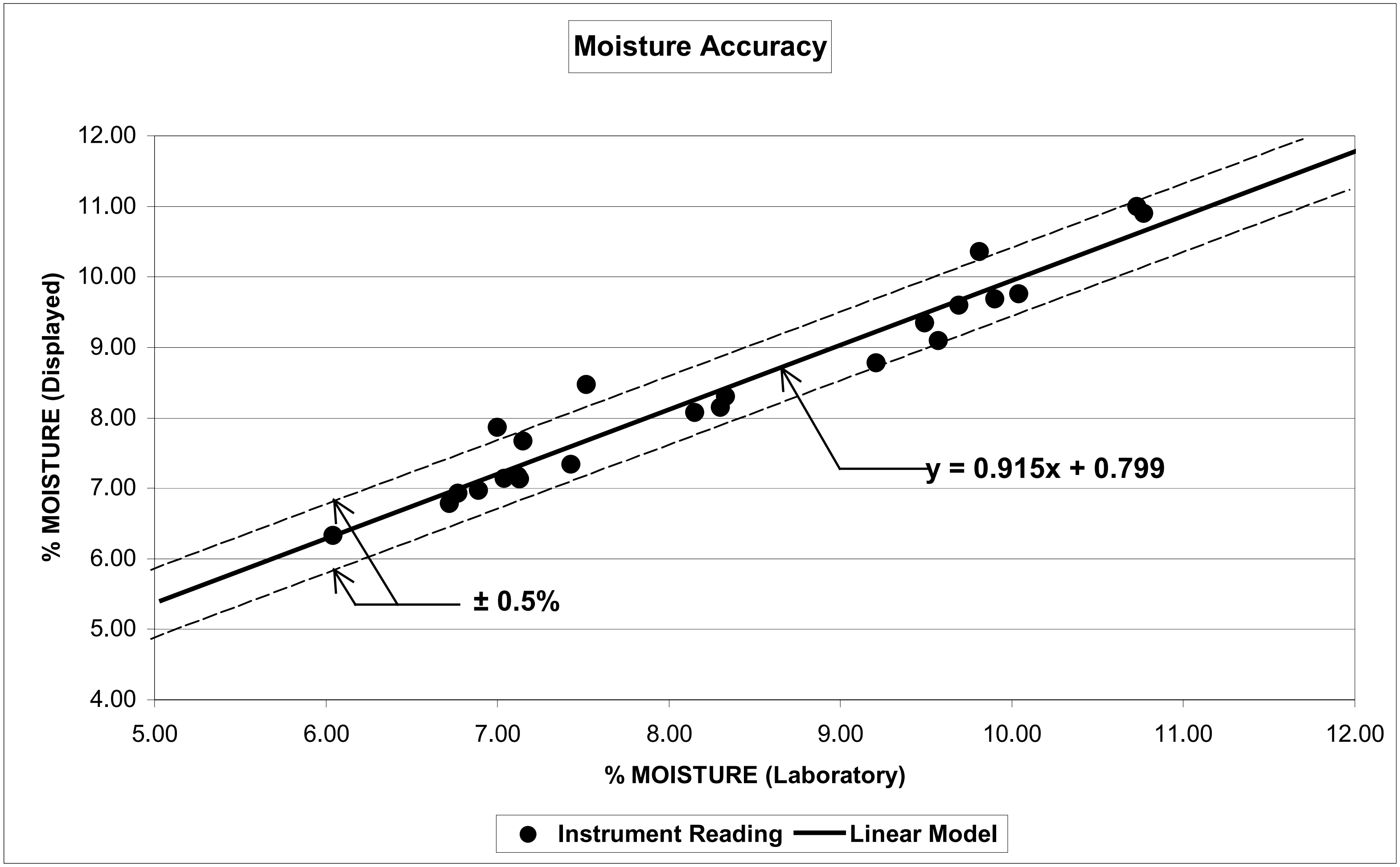


Figure 3: Verification of the Moisture Instrument Value for Zn Concentrate

The verification procedure confirmed a correlation coefficient of 0.969 within the measuring range of 6 to 10 % moisture and the absolute accuracy was generally within ± 0.5 % of laboratory moisture content.

Time	% Moisture Sensor 1 per sec	% Moisture Lab. Grab Sample/Loss In weight 1 per 15 min	% Differential
17:00	9.63	9.9	0.27
17:01	9.52	-	-
17:04	9.77	-	-
17:10	10.42	-	-
17:14	10.89	10.77	0.12
17:16	10.96	-	-
17:30	10.98	10.73	0.25
17:31	11.00	-	-
17:58	10.64	-	-
17:59	10.49	-	-
18:00	10.3	9.81	0.49
18:04	8.08	-	-
18:10	6.92	-	-
18:15	6.69	6.72	0.03
18:20	7.62	-	-
18:30	8.17	-	-
18:35	7.76	-	-
18:40	8.02	-	
18:45	7.86	7.0	0.86
18:50	8.02	-	-
18:55	8.36	-	-
19:00	8.43	7.52	0.91
19:05	7.83	-	-
19:10	7.83	-	-
19:20	8.28	-	-
19:25	8.13	-	-
19:30	7.78	-	-
19:40	8.58	-	-

Table 2: % Moisture Sensor vs. % Moisture Lab. During a Disturbance Period

During the disturbance period starting at approximately 17:10 the moisture values approached and then exceeded 11 % resulting in the sensor output going to the maximum for the selected transducer. Normal operation of the process started at about 18:10, and the transducer signal began responding to changes in moisture content.

The second application is on-going at the Noranda Horne Slag Concentrator measuring copper slag on an intermittent load vacuum filter discharge belt. The same prototype sensor equipment used at Brunswick was installed. Table 3 illustrates the material parameters for the measurement with the working prototype tested on intermittent Noranda Horne Slag Concentrate.

Material	Cu Smelter Slag Concentrate
Normal moisture range	7-10 %
Flow rate range	20-30 t/hr (intermittent)
Particle size	60 % - 325 Mesh (44 µM)
Speed of belt	1.25 ft/sec

Table 3: Cu Slag Concentrate Intermittent Load Measurement Parameters

This application proved to be a challenge during irregular load conditions it was not possible to collect valid signals from the force transducer. The concentrate from vacuum or pressure filters discharges intermittently, which forms lumps of material on a conveyor belt. The application required more complex signal processing and averaging to achieve a valid moisture reading. Figure 4 illustrates the prototype equipment as installed on the concentrate discharge belt at Noranda Horne Slag Concentrator.

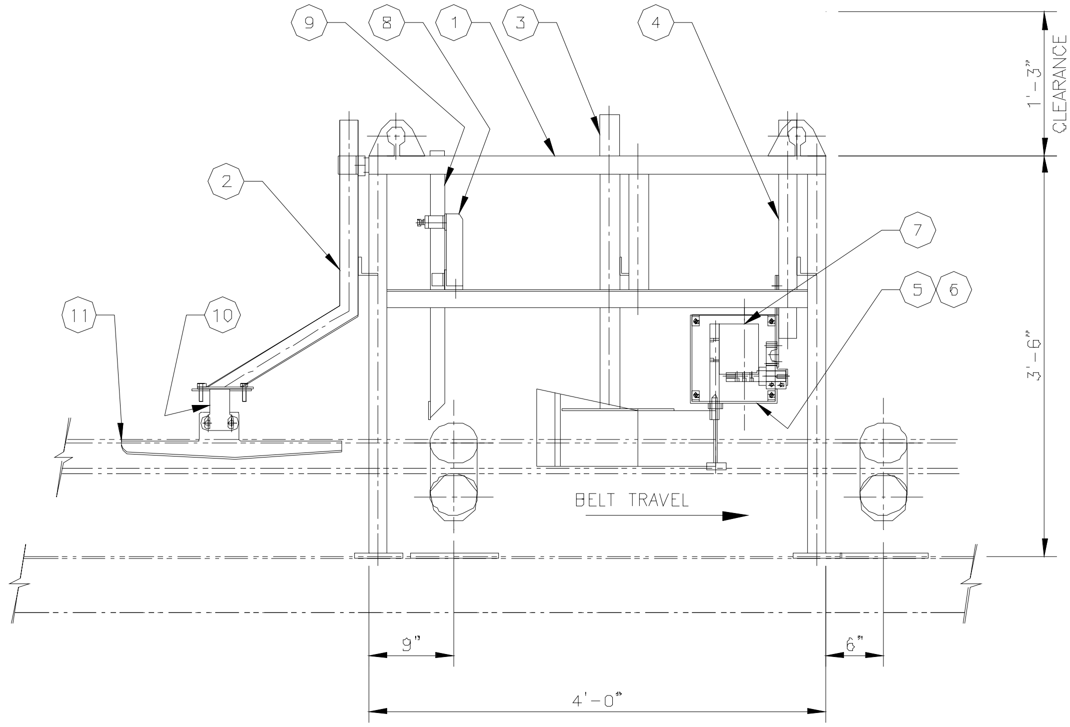


Figure 4: The Noranda Horne Prototype Equipment Installation

Description of Prototype Equipment Installation

In Figure 4, the direction of concentrate flow is indicated by the belt travel arrow. The load is shaped and gathered before reaching the force transducer (7), which comprises a stainless disk coupled to a stainless steel rod. The drag force transducer is protected from the environment by a transducer guard (5), complete with access door (6). The transducer guard is secured to the belt installation frame (1), and adjustable mounting bracket (4). The bulk thickness of the material in front of the force transducer is adjusted to a constant height by a depth control plough (3). A material guide (10,11) is installed on an adjustable bracket (2) ahead of the plough to encourage mixing of material particles from the outside to the centre of the belt. During low flow rate periods, the material guide is helpful for gathering material to the centre of the belt. For high flow rate periods, a clump clipper (8,9) limits the height of each material clump.

Preliminary Observations of the Test Measurement in an Intermittent Load

- Mineral concentrate flows in clumps during a number of seconds, typically 10 to 15 seconds of material flow followed by 5 to 8 seconds of little or no flow.
- During the 10 to 15 periods of normal material flow the transducer signal was found to be similar to Brunswick's case.
- The profile of intermittent material on a moving belt gives a saw-tooth waveform signal from the transducer, as the clumps pass the measurement location.
- The saw-tooth signal was not representative for correlation to moisture content.
- Special software features must be designed and programmed.

Discussion on Work Completed to Date and What is Next

It has been 14 years since K. Carr-Brion suggested in his book that the mechanical properties of powders, such as cohesiveness and resistance to flow, could be put into practice to measure the moisture content of granular materials. Although there is a need yet for an on-line sensor for moisture, no viable solution has been found. The new innovation introduced is promising but the lack of resources and process control priority shifts both contributed to the timing when development projects gain acceptance. For example, although the results were encouraging at Brunswick in 1997, all testing stopped as people and priorities changed in the plant. Recently, interest at Brunswick has renewed and further testing of the material will resume after The Horne test is completed early in 2001.

At Noranda Horne, innovative software was required in order to filter the irregularities in the depth of material as clumps passed the measurement location. The software filter conditions the signal and rejects all data under pre-determined conditions, i.e., such as clumps too short or clump signal noise too large. The force transducer signal is read continually, i.e., every 0.1 of a second, ten times the rate used at Brunswick case. This allowed only valid data from clumps to be tabulated into a running average. One new moisture value is then calculated after a pre-set number of clumps have passed the sensor. The calculated average moisture value, based on a linear model, is output to a local display and process computer.

The software filter is scheduled for installation at the site in the fall of 2000 with calibration taking place immediately followed by measurement verification. Although calibration results and measurement verification were not available at the time of publishing the CMP proceedings, based on the experience already gained, with the equipment, there is no reason to doubt similar results will be achieved with copper slag concentrate at Noranda Horne as seen with zinc concentrate at Brunswick. The testing work is continuing and will be presented January 2001, at the CMP conference in Ottawa.

Conclusions

- Timely measurements of moisture content in ore concentrates remains a necessity for control of de-watering processes and thereby reduced treatment costs.
- The measurement of moisture content by traditional methods has proved to be either time consuming, technically complex or costly when considering ore concentrates.
- The mechanical properties of granular materials, such as cohesiveness and resistance to flow, are key in estimating the presence of water with the drag force principle.
- The drag force principle demonstrated a reliable method of determination of moisture content in ore concentrates.
- The test work completed on the new moisture sensor for continuous and intermittent load concentrate belts will lead to other applications in the area of reducing de-watering costs, water moisture consistency and moisture determination for concentrate shipments.

Acknowledgements

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Table 4: Moisture Measurement Methods Available for Granular Material

Technique	Principle	Advantages	Disadvantages	Applications
Standard Gravimetric Method Commonly known as loss in weight method	- Drying at a controlled temperature to evaporate free water - Weighing the remaining dry weight	- Measurement is absolute	- Laboratory scale & drying system required in field - Sample must be representative of the whole bulk - Delays in receiving results	- Currently the method of choice in majority of the base metal ore concentrator applications - Provides the basic calibration required for on-line process measurements
Microwave Phase shift	- Transmission of low energy focused microwave beam through material - Measurement of beam changes due to water content	- High accuracy and low detection limit - Medium to high price depending on optional features - Less sensitive to the effects of dissolved electrolytes - Effects of bulk density can be compensated	- Relative investment high - System complexity high - Dependant on bulk density of material - Affected by any metal structure in the microwave transmission path	- Coal - Non-conducting minerals - Food products - Wood products - Grain - Ceramics - Carpets
Microwave Attenuation	- Transmission of low energy focused microwave beam through material - Measurement of beam changes due to water content	- High accuracy and low detection limit - Less sensitive to the effects of dissolved electrolytes - Bulk density can be compensated	- Relative investment high - System complexity high - Dependant on bulk density - Affected by metal structure in microwave transmission path	- Coal - Non-conducting minerals - Food products - Wood products - Grain - Ceramics - Carpets
Capacitance, conductivity and radio frequency are all similar. Definitions associated with this technique. “The Penguin Dictionary of Physics” *Absolute permittivity*: “The measure of the degree to which a medium can resist the flow of charge. The absolute	- Huge difference in dielectric constant of water compared to most common host materials - Permittivity of water compared with dry materials - Examples of relative permittivity - Glass: 5-10 - Paper: 2 - Mica: 6 - Polythene: 3	- Relative investment low	- Sensitivity to inter-elemental affects - Dependant on bulk density of material - Interference from variation in the concentration of dissolved electrolytes within the material - Must be re-calibrated frequently	- Wood products - Capacitance method has had some success with mineral sands - Radio frequencies is similar to capacitance method only with better and frequency tuning - Possible solution for mineral processing applications

Technique	Principle	Advantages	Disadvantages	Applications
permittivity of free space or vacuum is called the electric constant.” *Relative Permittivity*: “The ratio of absolute permittivity of a medium to the electric constant.”	- Ice: 94 - Oil: 5 - Paraffin wax 2 - Methanol: 32 - Water: 81			
Near Infra–Red	- All forms of water strongly and selectively absorb infra-red radiation - Based on the characteristic absorption bands of water, which are broad due to hydrogen bonding.	- Medium to high accuracy. - Non-contact with material - Large range of applications - Medium priced	- Surface dependant - Beam affected by dust and interferences such as steam and high humidity - Reflective and black colour surfaces cause false readings - Chemical interference to beam	- Common method for moisture in gases - Wood chips - Tobacco - Food & cereal products - Pharmaceuticals - Pigments - Paper fibres - Ceramic powders - Corn starch
Radio Frequency Transmission	Sensor frequency relates to material dielectric properties.	- Medium accuracy - Medium investment	- Inter-elemental effects - Thickness dependant	- Wood chips - Grains - Wood board products - Textile products - Foods & cereals products - Possible solution for mineral processing applications
Neutron moderation activation	- Determined by concentration of hydrogen atoms in the material - Moisture content is Inferred	- High accuracy over wide moisture range - Can be transmitted through large volumes - High relative investment	- Nuclear licence required - Not an accepted method for the food industry - Bulky & complex system - Deep penetration	- Powders - Coke & coal - Cement slurries - Iron ore sinter, steel - Non-ferrous metals - Possible solution for mineral processing applications
Low Resolution Nuclear Magnetic Resonance (NMR)	- Specific for hydrogen atoms in liquids	- High accuracy over wide moisture range - High relative investment	- Nuclear licence required - Not an accepted method for the food industry - Bulky & complex system	- Building materials - Cement slurries - Coke & coal - Possible solution for mineral processing applications

References

Albert, R., Pfeifer, M.A., Barabási, A.-L., and Schiffer P., “Slow Drag in Granular Motion”, Physical Review Letters, 82, 205-208 (1999)

Albert, I., Tegzes, P., Kahng, B., Albert, R., Sample, J.G.,Pfeifer, M.A., Barabási, A.-L.,Vicsek, T., and Schiffer, P., “Jamming and Fluctuations in Granular Drag”, Physical Review Letters, 84, 5122 (2000)

Barabási,A.-L, Réka, A., and Schiffer, P., “The Physics of Sandcastles: Maximum Angle of Stability in Wet and Dry Granular Media.” Department of Physics, University of Notre Dame, (1998)

Carr-Brion, K., “Moisture Sensors in Process Control”. Elsevier Science Publishing Co., Inc., New York. , (1986)

Cornish, D.C., Jepson, G., and Smurthwaite, M.J., “Sampling Systems for Process Analysers, Butterworths, London, (1981)

Edwards, R.P., and Flintoff, B.C., “ Process Engineering of Flotation Circuits”, Proceedings - 26th Annual Meeting of the Canadian Mineral Processors, Ottawa, (1994)

Konigsmann, K., and Flintoff, B.C., “Information Technology in Mineral Processing, Smelting and Refining”, Proceedings from A workshop for Senior Executives, Session on Plant Automation, pg. 87-88, Ottawa, (1990)

Marinigh, M.J., and Cancilla, P.A., “Implementation of Good Sampling in Mineral Process Plants”, Proceedings- Canadian Mineral Processors, North-West Quebec Regional Meeting, Rouyn-Noranda, (1996)

Rosenblum, F., Interviews and technical reviews, “Draft of Letters of Patent for Moisture sensor for ore concentrates and other particulate materials”, (1999)

Other References

Various vendor data sheets and website for On-Line Moisture Instruments
Near Infra-Red (NIR)
Capacitance, conductivity & radio frequency instruments
Micro Wave Analyzer with bulk density compensation
The Penguin, “Dictionary of Physics”
www.harcourt.com/dictionary
www.moisturesensors.com
www.processsensors.com
www.ndcinfrared.com
www.arnoldgmbh.com
www.lignomat.com