On-Line Moisture Determination of Ore Concentrates — A Review of Traditional Methods and Introduction of a Novel Solution

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ABSTRACT

The manual gravimetric drying moisture determination methods currently employed by most mineral processing plants fail to provide timely and accurate information required for automatic control. The costs associated with transporting and handling concentrates 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, any tool that provides real-time feedback on the process is vital (Edwards, RP 1994). The introduction of an on-line moisture sensor would become a welcome addition to the process control field instrumentation package now applied. A novel on-line determination system for ore concentrate moisture content would replace the tedious 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, (Konigsmann, 1990). Today, the task of moisture determination is still done by the classical technique of loss in weight utilising 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 seven to nine percent, but controlling the moisture content below eight percent is a difficult task with a manually controlled system. Many times, delays in manually achieving reliable feedback of the moisture content results in the moisture varying from five to twelve percent 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 introduces and describes a unique and promising novel on-line moisture sensor employed for mineral processing de-watering applications, which not only automates the tedious tasks but also results in reliable moisture feedback that can be used in the optimisation 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 summarise the measurement requirements for the proposed method of employing drag force and mechanical properties of the material itself to determine the moisture content. The commercial model of the equipment is described with the features and benefits to the users summarised.

INTRODUCTION

Although it has been approximately 40 years since on-line methods have become common in industrial applications, they have not become widely accepted or standardised in mineral processing plants for a number of physical property reasons. Commercial sensors to measure particulate and granular moisture content have been available for laboratory use for many more years. These devices use physical principles or properties of the material under measurement to categorise the measurement methods. These properties include electrical conductivity, dielectric properties, microwave absorption and radio frequency transmission. Each is affected by the electrical properties of conductive ores such as copper, lead and nickel concentrates, or the contained water, and therefore cannot be reliably applied. The errors with conductivity-based measurements also make them difficult to apply 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 analysed. The measurement is also affected by the concentrate's optical absorption at wavelengths used to characterise 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. These systems are generally bulky and heavy due to the required lead shielding used to diffuse the radiation emitted. Also, they 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 provided in Table 1. From this summary, it is evident that there is a common lack of acceptance, in mineral processing, of the current available on-line moisture technologies and more investigation would be required to find a reliable solution that is less influenced by the material's physical characteristics such as; temperature, homogeneity; particle shape, colour and other properties.

The conclusions formed by the Noranda Technology Centre inventors, after reviewing the many available technologies, led 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, 1986). The sensor should employ the mechanical properties of the particles such as drag force and the resistance to flow to equate the moisture content of the bulk material. Table 2 provides a comparison of the novel on-line moisture measurement determination utilising the drag force principle for various granular material applications.

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TABLE 1

Comparison of common on-line moisture measurement methods for granular material (Carr-Barion, K, 1986; Spitzlei, M, 2000; and Process November 2002, CSIRO Minerals on the web).

Principle and technique	Advantages	Disadvantages	Applications
Standard Gravimetric Method Commonly known as loss- in-weight method. Drying at a controlled temperature to evaporate free water. Periodic weighing to determine the remaining dry weight.	• Measurement is direct, and reproducible when representative samples are required.	• Laboratory scale and drying system required near process. • Sample must be representative of the whole bulk material. • Delays in receiving results.	• Currently the method of choice in majority of the base metal ore applications. • Provides the basic calibration required for on-line process measurements. • Portable microprocessor controlled analysers are available which will provide the result in 10-20 minutesdepending on the application.
Microwave Phase shift Transmission of low energy focused microwave beam through the measurement medium. Energy 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. • Needs compensation for bulk density variations.	• Coal. • Non-conducting minerals. • Food products. • Wood products. • Grain. • Ceramics. • Carpets. • Pharmaceuticals.
Microwave Attenuation (conventional technology) Transmission of low energy focused microwave beam trough the measurement material. • Measurement beam changes due to water content.	• High accuracy and low detection limit. • Less sensitive to the affects of dissolved electrolytes. • Bulk density can be compensated.	• Relative investment high. • System complexity high. • Affected by metal structure in microwave transmission path. • High influence from particle size. • Needs compensation for bulk density changes. • High attenuation of signal in many granular materials.	• Coal . • Non-conducting minerals. • Food products. • Wood products. • Grain. • Ceramics. • Carpets.
Near Infra-Red (NIR)	• Medium to high accuracy. • Non-contact with material. • Large range of applications. • Medium investment.	• 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. • Affected by particle surface characteristics. • Medium influence from particle size.	• Common method for moisture in gases. • Wood chips. • Tobacco. • Food and cereal products. • Pharmaceuticals. • Pigments. • Paper fibers. • Ceramic powders. • Corn starch. • Ideal for thin film applications.
Capacitance, conductivity and radio frequencies 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 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.'	• Relative investment low. • Capacitance probes have low affect from ambient temperature.	• Sensitivity to mineral inter-elemental effects: ie when measuring zinc concentrate the amount of iron can affect the moisture content indication. • Dependant on bulk density of material. • Interference from variation in the concentration of dissolved electrolyteswithin the material. ie the quality of process water can affect the moisture indication.	• Wood products. • Some success with mineral sands. • Foods, cookies, cereals. • Grains. • Possible solution for some mineral processing applications.

TABLE 1
(Continued)

Principle and technique	Advantages	Disadvantages	Applications
• Measurement of the huge difference in dielectric constant of water compared to the most common host materials. • Permittivity of water compared with dry materials. Examples of relative permittivity: • Glass: 5-10. • Paper: 2. • Mica: 6. • Polythene: 3. • Ice: 94. • Oil: 5. • Paraffin wax 2. • Methanol: 32. • Water: 81.		• For the above reasons the equipment must be re-calibrated frequently	
Radio Frequency Transmission • Radio frequencies is similar to capacitance method only with better frequency tuning. • Sensor frequency relates to material dielectric properties.	• Medium accuracy. • Medium investment.	• Inter-elemental effects. • Thickness and bulk density dependant. • Medium to high influence from particle size.	• Wood chips. • Grains. • Wood board products. • Textile products. • Foods products, cereals and cookies. • 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. • compared to all methods, less affected by particle size, bulk density and material's physical characteristics.	• Nuclear license required. • Not an accepted method for the food industry. • Bulky and complex system. • Deep penetration. • High relative investment.	• Powders. • Coke and 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.	• Flow and temperature dependent. • Heavy magnet required for sensing head. • Magnetic materials may cause problems.	• Building materials. • Cement slurries. • Coke and coal. • Possible solution for mineral processing applications.
Low Frequency Microwave (LRM, phase shift and attenuation) • relatively new technology that allows transmission through thick depths of highly attenuating materials.	• Investment not currently published. • Problems with conventional microwaves seemed to be overcome. • Good accuracy (0.1-0.3 wt% typically).	• Top size up to 300 mm. • Commercial version is new. • Good accuracy with iron ore and coal other materials are under review is dependant on bed depth.	• iron ore, coal loading. • testing on high flow rates (up 10 000 t/hr) and thick bed levels (650 mm), depth correction required.

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, which 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.

TABLE 2

Comparison of novel on-line moisture determination for granular material applications.

Principle and technique	Advantages	Disadvantages	Applications
Direct physical measurement based on the drag force principle: the drag force applied to a stationary object in a granular medium is dependant on the particle size, the surface tension and cohevesiveness, the depth the object is inserted in the medium and the diameter of the object. $F_d = \eta g \rho H^{2-2.5}\ d_c$ where: η = characterises 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	Directly dependent on the moisture properties of material under measurement. • Moderate investment. • For mineral concentrates and granular materials not dependant on a number of limiting parameters present with other techniques (ie colour, conductiveness, dielectric constant and temperature). • No inter-elemental affects. • Continuous measurement of the bulk moisture content.	• Variable particle size of same medium can cause measurement errors (can be compensated with multiple calc. model selections). • Bulk density variations (as above can be compensated). • Belt loading variation (can be compensated with multi-variable calc. model). • Accuracy limited to +/- 0.3% within a range of 5 to 15% moisture.	• De-watering process of mineral concentrates (ie Cu, Ni, Zn and Pb). • Glass beads. • Steel making slag. • Industrial minerals (ie talc, silica sand and potash). • Limestone, cement. • Iron concentrate feeding pelletising plants. • Powder materials (ie ceramic powders).

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; ie 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, 1986).

Sampling considerations for the calibration of on-line moisture sensors (Cornish *et al*, 1981)

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; and
- samples are adequate enough in water content range to clearly delineate the calibration graph.

PHYSICAL PRINCIPLES OF GRANULAR MATERIALS

Much can be learned by studying how granular material behaves as contended by physicists, Even a small improvement in our understanding of granular media could have a profound impact on industry' (Peterson, 1997). Granular materials display a curious blend of properties. Dry sand, for example can be poured like a liquid. Unlike a liquid, however, it can also support the weight of objects like a person walking on a beach. The contact forces between grains in a pile of granular material transfer weight to the outside or to the walls of a container, such as a silo. The forces are not distributed evenly throughout the material. The column's weight is carried from grain to grain along jagged chains ie a network of lightning bolts of concentrated force. As a result, the container's walls rather than its base carry much of the weight. The force is significantly larger at some points of contact than at others. The experiments were conducted by physicists Jaeger and Nagel of the University of Chicago and Behringer of Duke University. The presence of, what Nagel and his colleagues call, force chains may account for the sudden failure of the side walls of a silo, when grain columns happen to apply an enormous force to a particular weak spot. The force chains were visualised by studying the behavior of a static pack of spherical beads in a compression cell as shown in Figure 1. The force chains are the key to the further development and implementation of the drag force principle for determining the moisture content of granular material. The complete results of the experimentation were reported in October 1996, 'Review of Modern Physics'.

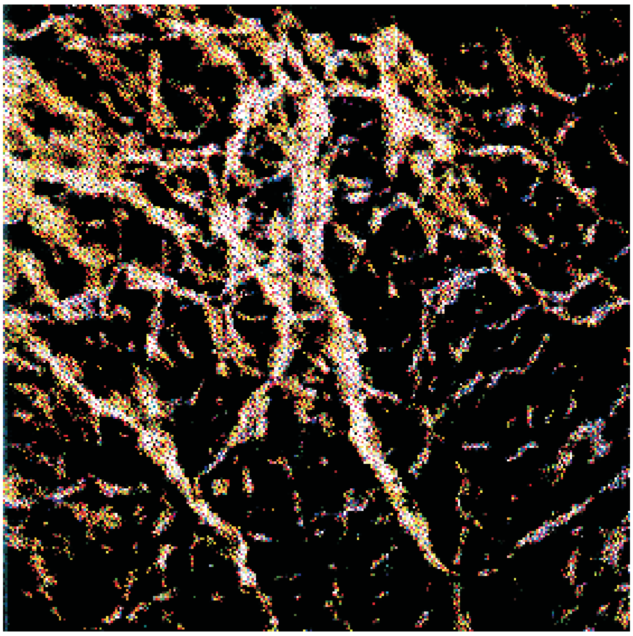


FIG 1 - Photo image of the force chains in granular material (Peterson, 1997).

The image above was obtained by viewing pressure-induced changes of the polarisation of light, transmitted through a 3D packing of glass spheres. Before pressure was applied from the top, crossed polarisers were arranged such that no light was transmitted through the pack. After the external pressure was applied, force chains appeared as bright lines in the above picture. To prevent light scattering and reflections, the beads were immersed in an index-matched fluid. The stressed beads appear as bright spots.

INTRODUCTION OF THE NOVEL ON-LINE MOISTURE SENSOR

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, 1999).

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 Albert, R, *et al* (1999). 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 functional form as shown Equation 1:

$$F_d = \eta g \rho H^{2-2.5} d_c \tag{1}$$

where:

η = characterises 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 Albert, *et al* (1999). 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 2 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 helped 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. The dependence factor for depth (H) can vary from a power of two to two and half depending on the granular media under measurement. The F_d principle is dependent on continuous mechanical properties of the material

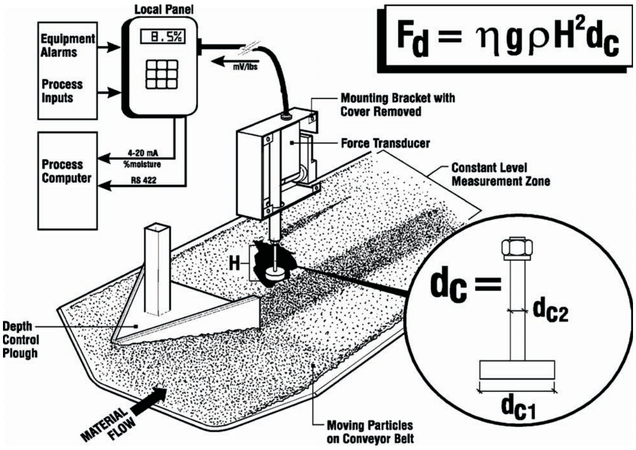


FIG 2 - Artist illustration of the drag force principle used to determine the moisture content in a granular medium on a moving belt.

such as resistance to flow associated with surface friction and packing fraction of 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 a little bit of 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 2 also indicates that for a given material, the only measurement parameters which must be controlled for a true determination of moisture content equated from the F_d principle is the bulk thickness of material against the sensor's rod and disk. The results of two papers published by Prof. Schiffer and his team titled 'Slow Drag in a Granular Medium' (Albert *et al,* 1999) and 'Granular Drag on a Discrete Object: Shape Effects on Jamming' (Albert *et al*, July 2001) are shown in Figure 3 and Figure 4.

Albert et al. Figure

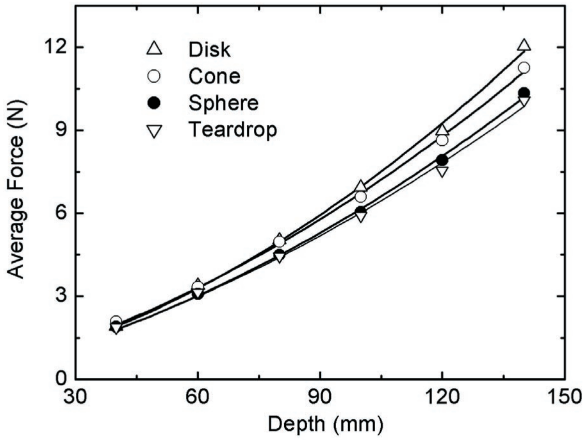


FIG 3 - Comparison of drag force on different shapes, where depth (mm) is the vertical distance the cylinder was extended into the granular material (Albert *et al*, 2001).

The conclusion of this experiment found that the measured force difference between the disk and the teardrop was no more than 30 per cent. This was a significant fact since for fluids the variations can be more than 300 per cent (Albert *et al*, 2001).

In the experiment a vertical cylinder of diameter (**d$_c$**) was extended a distance H into a bucket of granular material and held fixed while the bucket was slowly rotated. The granular medium consisted of glass spheres with diameters (**d$_g$**) = 0.41, 0.05, 0.88, 0.03 and 3.0 mm. The rotating bucket was constructed with an open central tube through which a concentric shaft was mounted on low friction bearings. The cylinder which extends into the medium was mounted on an arm fixed to the same shaft which is mechanically isolated from the rotation of the bucket except through the torque on the cylinder from the granular medium. The arm holding the cylinder is held fixed (ie preventing from rotating with the bucket) by the sensor of a load cell which measures the stopping force which is equivalent to F_d (Albert *et al*, July 2001; Albert *et al*, 2000). The depth dependence of F_d is shown in Figure 4 for several combination of **d$_c$** and **d$_g$**. The results of this experimentation lead to suggestions of further investigation of other properties of granular media, such as of correlations due to the presence of interstitial liquid and the confirmation of the theory behind the novel sensor for determine the moisture content of granular material ie mineral concentrates.

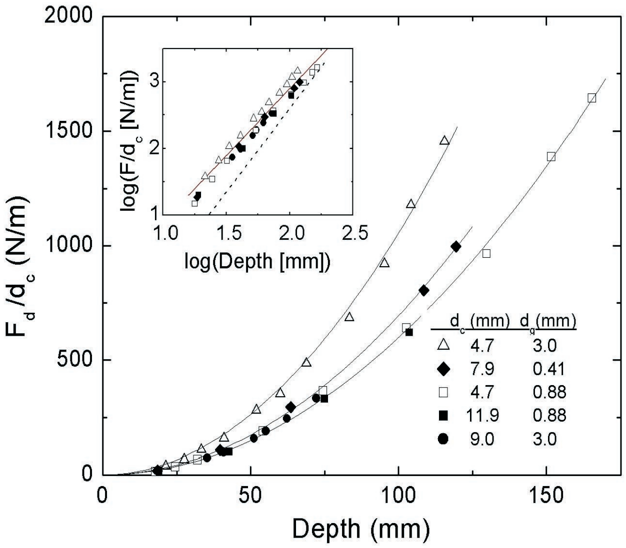


FIG 4 - The depth (H) dependence on the drag force (F_d). Where d_c (mm) is the cylinder diameter and d_g (mm) is the grain size (Albert *et al*, 1999).

CASE STUDIES OF NOVEL ON-LINE MOISTURE DETERMINATION

Case 1. Continuous loaded Zn concentrate belt at Brunswick Mining and Smelting (BMS)

The first application was completed in 1997 at Brunswick Mining and Smelting, Bathurst, New Brunswick, Canada. The material under measurement was Zinc concentrate (Zn Conc.) on a continuous load belt. Table 3 illustrates the material parameters for the measurement with the working prototype tested on Zn Concentrate.

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 see Table 4 for the BMS observations of grab sampling. The verification procedure confirmed the sensor was producing acceptable results. The tracking plot, Figure 5, of the sensor moisture measurement shows only slight differences between the laboratory analyses of the check samples taken every 15 minutes.

TABLE 3

Brunswick mining and smelting (Zn. Conc.) continuous load measurement parameters.

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

TABLE 4

Brunswick Mining and Smelting, per cent Moisture Drag Force method versus per cent Moisture Loss-In- Weight method.

Time	% Moisture (Avalanche) 1 per sec	% Moisture Lab. Grab sample loss in weight (1 per 15 min)	% Diff
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		

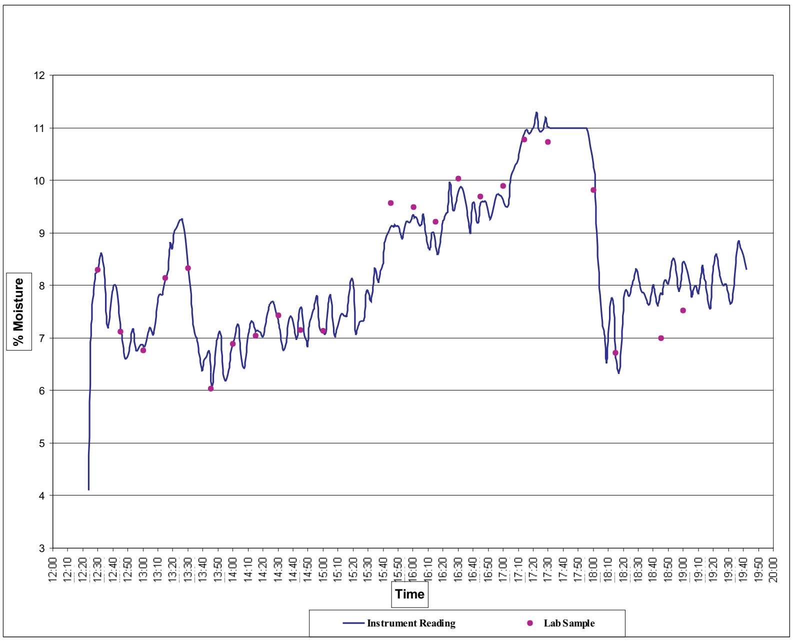


FIG 5 - Brunswick Mining and Smelting Shift report of on-line moisture measurements determined using the drag force method showing ten minute corresponding grab verification samples per cent moisture (laboratory) indicated by the symbol (•).

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 full scale limit of the transducer is indicated at time 17:31 to 17:56 on Figure 5. During this period, the moisture reading was very high at 11 per cent, 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 sensor to moisture content of Zn Conc. was achieved and measurement verification was possible, see Figure 6.

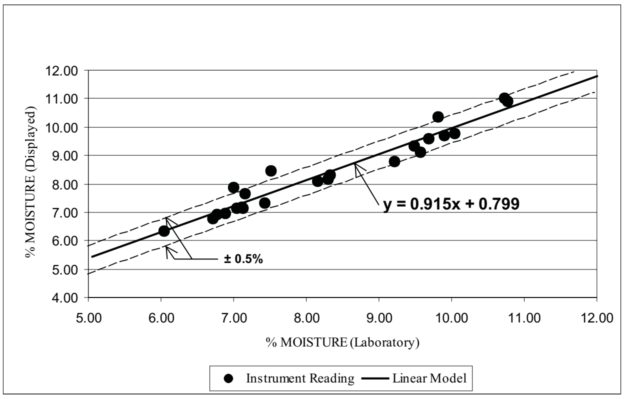


FIG 6 - The verification results from Brunswick Mining and Smelting calculated moisture (displayed) value achieved correlates very strongly to the laboratory moisture of the grab samples used for calibration. The accuracy limits of ± 0.5 per cent are shown by the dotted line to validate the sensor performance.

During the disturbance period starting at approximately 17:10 the moisture values approached and then exceeded 11 per cent 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.

Case 2. Intermittent loaded Cu slag belt at Noranda Horne slag concentrator (NH-Slag.)

The second application is on-going at the Noranda Horne Slag Concentrator, Noranda, Quebec for Copper Slag Concentrate (Cu Slag Conc.) on an intermittent load vacuum filter discharge belt. The same prototype sensor equipment used at Brunswick was installed. Table 5 illustrates the material parameters for the measurement with the working prototype tested on intermittent Noranda Horne Slag Concentrate. 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.

TABLE 5

Noranda Horne-Slag, intermittent load belt measurement parameters.

Material	Cu Slag Conc.
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

Preliminary observations of the test measurement in an Intermittent Load

- Material flows in lumps during a number of seconds, typically ten to 15 seconds of flow followed by five to eight seconds of little or no flow.
- During the ten to 15 periods of normal material flow the transducer signal was found to be similar to BMS's case.
- The profile of intermittent material on a moving belt gives a saw-tooth waveform signal from the transducer, as the lumps pass the measurement location.
- The saw-tooth signal was not representative for correlation to moisture content therefore special software features must be designed and programmed. (See Figure 7).

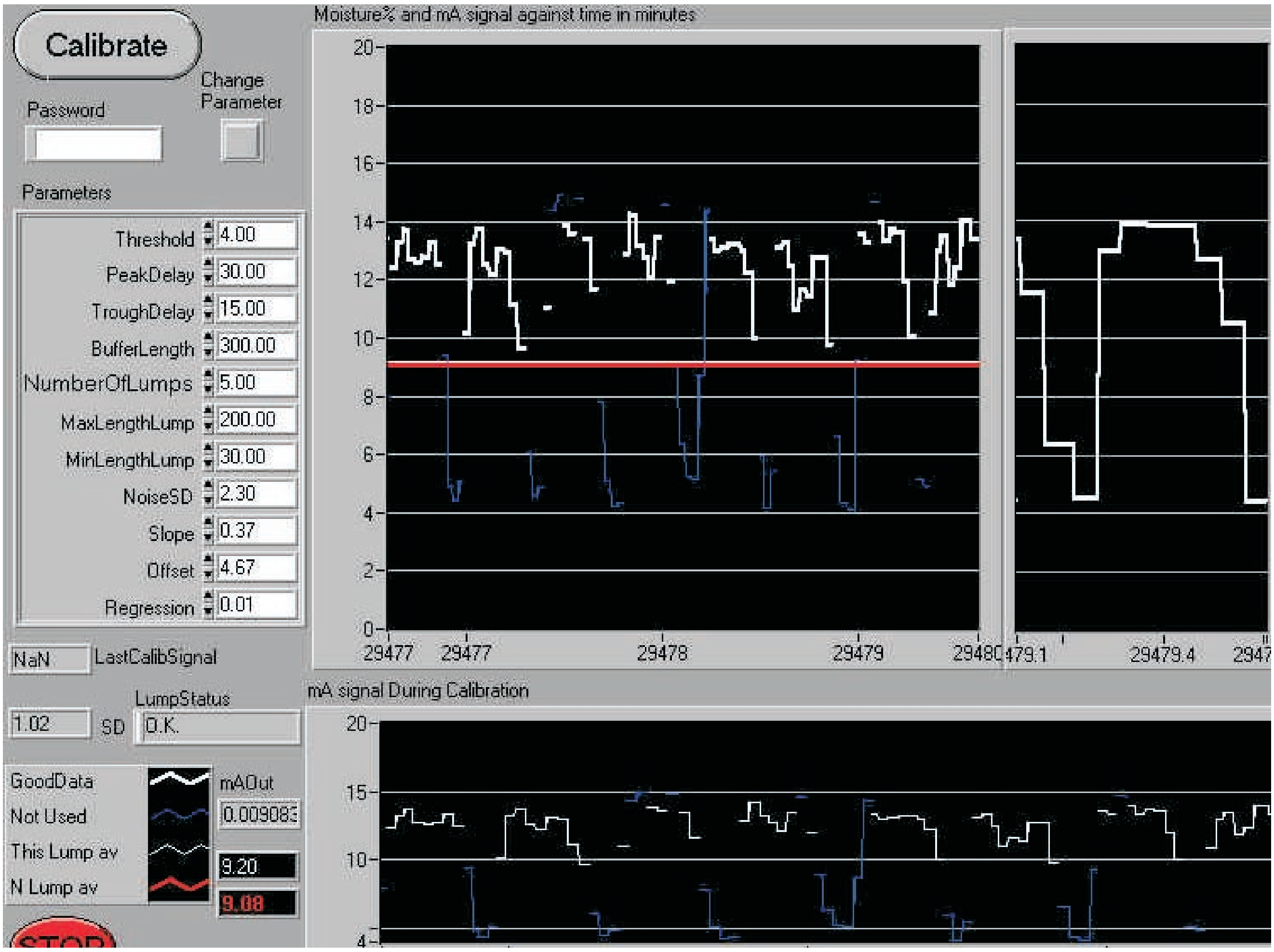
The innovative software was developed in order to filter out the invalid data during the time no material was present or the loading was below a pre-set threshold. As the sensor passes from a trough to a lump the signal goes to near zero and then to maximum. The software filter conditions the raw signal and rejects all data under pre-determined parameters, ie such as lumps too short or lump signal noise too large. The force transducer signal is read continually, ie every tenth of a second, in order to provide a large set of numbers. The signal conditioning allowed only valid data from lumps 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 location. The calculated average moisture value is based on a linear model and is output to a local display plus the process computer (DCS). The bottom view is the Calibrate Screen when a button is pushed near the belt and grab samples are collected manually, the valid milli-amp input is averaged in this window and after the button is pushed again the average milli-ampere signal is produced as the reference signal for the corresponding sample. The sample is then sent to the laboratory for accurate moisture determination using the traditional loss-weight method. The procedure of grabbing samples is repeated until a good variation of samples are collected over the desired moisture range usually up to approximately 20, obtain a population of calibration samples which are then used in the linear regression program to produce a preliminary calibration model shown in Figure 8.

Description of prototype equipment installation

In Figure 9, 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) is installed on an adjustable bracket ahead of the plough to direct the load 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. To ensure the belt remains flat and constant at the measurement location a belt idler (11) was installed. The milli-volt signal produced by the force transducer (7) is converted by a signal conditioner to 4-20 milli-ampere analog signal for transmission to the data processing and display screen as shown in Figure 7.

DESCRIPTION OF THE DEWATERING PROCESS AT THE NORANDA HORNE CONCENTRATOR

The Noranda Horne slag milling circuit produces approximately 250 metric tons of copper slag concentrate per day. The concentrate is pumped to thickening where the pulp solid content goes from 65 per cent to 72 per cent. The thickened pulp is then stored in mixing stock tanks waiting to be filtered. The filtration plant operates approximately 16 hours per day depending on concentrate production. The pulp is pumped to a disk filter and for the solid-liquid separation sequence after which the concentrate falls on a series of conveyors to end up in a mobile container. The containers can accept a maximum load of 17 metric tons of concentrate and must be replaced regularly. This stoppage results in a disruption of the filter operation where the blow of the filter is stopped and the material pick-up on the sector is reduced to a minimum. At start-up of the filter, after each stoppage the filter cake has a higher moisture content for the first ten to twenty lumps. The filtration uses a dewatering agent to help reduce the moisture content of the cake. During the last two years the six sigma project has identified find ways to reduce the moisture content of the filtered cake. During the period from the first six months of 1999 to the last six months of 2000, the moisture content went from an average of 10.5 per cent, down to eight per cent through a number of process operation changes. As part of the six sigma methodology, a control plan to ensure these gains are maintained must be put into place. Part of the plan, a method to measure the filter cake moisture content on-line was targeted as the basic tool around which automation could be successful.



Password

Parameters

Threshold 4.00
PeakDelay 30.00
TroughDelay 15.00
BufferLength 300.00
NumberOfLumps 5.00
MaxLengthLump 200.00
MinLengthLump 30.00
NoiseSD 2.30
Slope 0.37
Offset 4.67
Regression 0.01

NaN LastCalibSignal

1.02 SD

LumpStatus O.K.

mAOut 0.009083

9.20

9.08

FIG 7 - Local display of software filter developed for the novel on-line moisture measurement.

Right window: raw analog input from force transducer. **Middle window:** the faint lines shows the invalid, rejected data and the bright line is the valid data. **Middle window:** calculated percent moisture content is the continuous gray tone trend line. **Left window:** user selectable parameters for clumps/trough definitions. **Bottom window:** display used to collect calibration data. Valid signal (mA) is totalised during calibration routine in the box labeled ‘Last Calib. Signal’ and is matched to the laboratory result and used to determine the regression results stored in the windows labeled ‘Offset’ and Slope’.

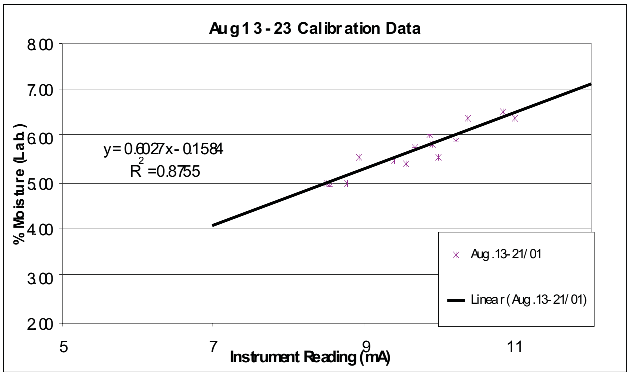


FIG 8 - Noranda Horne Slag, preliminary calibration model to calculate per cent moisture from the sensor instrument signal (milli-amperes).

The per cent moisture calculated in Cu Slag over time using preliminary calibration model. Upon detailed investigation the information proved to be useful but not ideal as found in Case 1 shown in Figure 5.

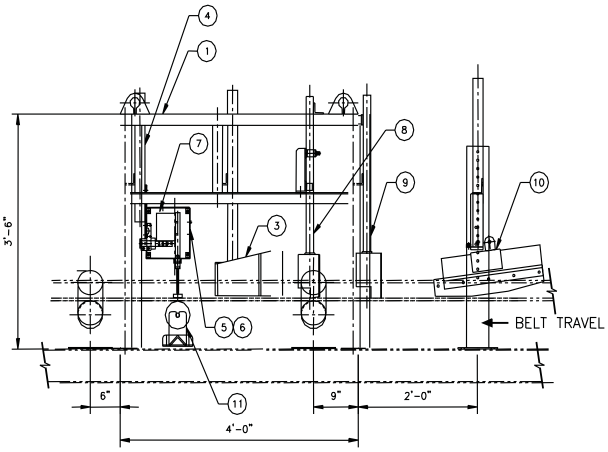


FIG 9 - The Noranda Horne Prototype equipment.

Evaluation of the preliminary results

On further investigation of the preliminary calibration model illustrated in Figure 8, it was found that the calculation model was highly affected by outliers points over a wider measurement range. Generally, the accuracy was acceptable in a narrow range between six to seven percent moisture. Figure 10 is the DCS trend line produced by moisture information coming from the novel on-line sensor. The information was useful but more work would be required with Case 2 material to find a more robust model which would make the long term stability and accuracy near the same quality as found with the continuous loaded conveyor in Case 1. In order to find a robust regression model more work was needed in gathering data from similar materials and collecting samples to determine the reasons for the lower then expected accuracy (Schumacker *et al,* 2002).

Further experimentation to improve the quality of the measurement results

After Noranda Horne testing of similar materials at varying feed rates a correlation was found confirming the suspicions that the wide range of tonnage had an effect on the applied drag force to the sensor. It was concluded that the packing fraction in front the sensor was changing with the tonnage through the expanded loading range 15 to 45 metric tons per hour (mt/hr). Figure 11 illustrates a very good correlation was found between the signal (mA) input and tonnage over the operation range. The mt/hr information was used at a variable in the calculation model to compensation for loading variation. The measurement results after implementing a multi-variable model was found to be more accurate see Figure 12. Also included is Figure 13, a 3D plot offering information on the physical relationship showing the relationship of per cent Moisture laboratory versus mt/hr and signal (mA) input. At this point in the development the moisture range was expanded to the widest limits of the process and the regression model was re-worked to find the most accurate and robust model possible. It was found that, as the moisture content increased toward ten percent moisture the drag force signal increased exponentially as oppose to the linear relationship found below nine percent. These results were in agreement with the principles introduced in the work done by Albert, *et al* and presented in 1999.

Table 6 illustrates the changes made to the characteristic models found for Noranda Horne-Slag Case 2, including the single variable linear model (2) the multi-variable linear (3) and finally the multi-variable squared model (4) based on the further experimentation conducted from August 2001 to January 2002. The experimentation enabled the calibration model to be expanded over a wider range of moisture content while maintaining high accuracy. From Figure 14, it can be seen that the final calculation model (4) found that 97.2 per cent of the observations lie within +/- 0.115 per cent of the laboratory moisture value (y-axis value) within the working range 7.22 to 9.29 per cent moisture.

CONCLUSION

The experiments and site testing provided results at the level suitable for reliable and accurate for process control applications.

- Timely measurements of moisture content in mineral ore concentrates remains a necessity for control of de-watering processes and thereby reduced treatment costs.

TABLE 6

Noranda Horne-Slag further experimentation to refine the calculation model comparisons of the calculation model.

NH- Slag Case 2	**Single variable linear calculation model**
Figure 8	$\% M = 0.6027 mA - 0.1584$ (2)
	Multi-variable linear model
Figure 12	$\% M = 8.97 - 0.1158 \text{ mt/hr} + 0.159 \text{ mA}$ (3)
	Multi-variable squared model
Figure 14	$\% M = 8.14 + 2.14 \text{ Ma} - 0.067 \text{ mt/hr} - 0.0593 \text{ mA}^2$ (4)

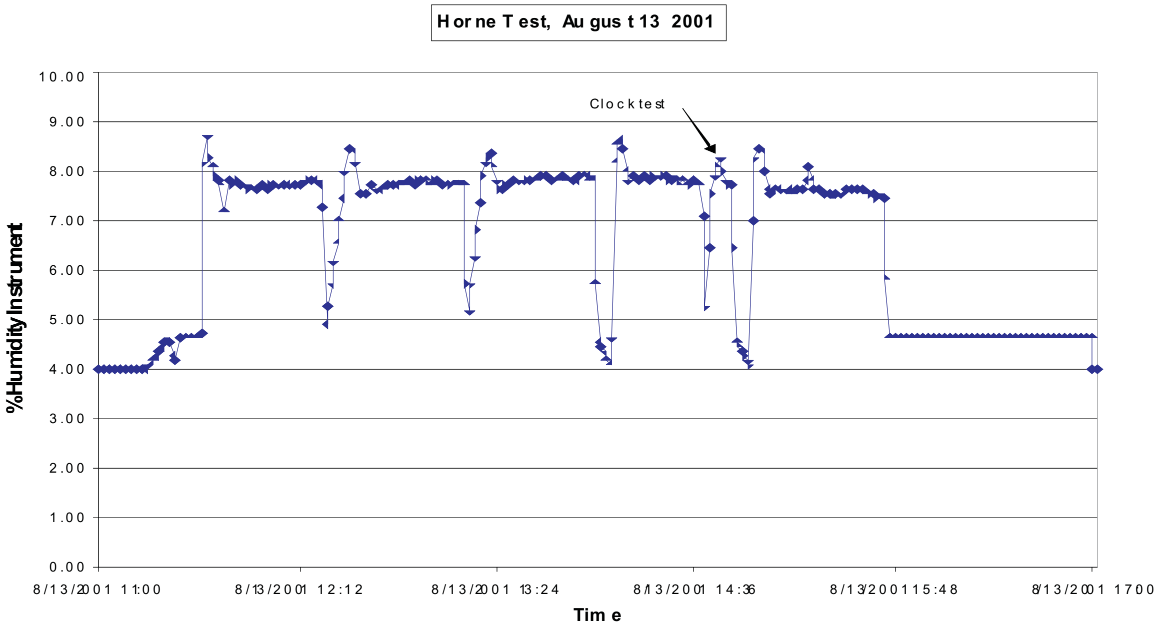


FIG 10 - Noranda Horne-Slag moisture history trend as displayed on plant distributed control system (DCS).

The per cent moisture calculated in Noranda Horne-Slag over time using preliminary calibration model was investigated in detail and determined to provide useful information but not up to the same level of accuracy as found in Case 1 shown in Figure 5.

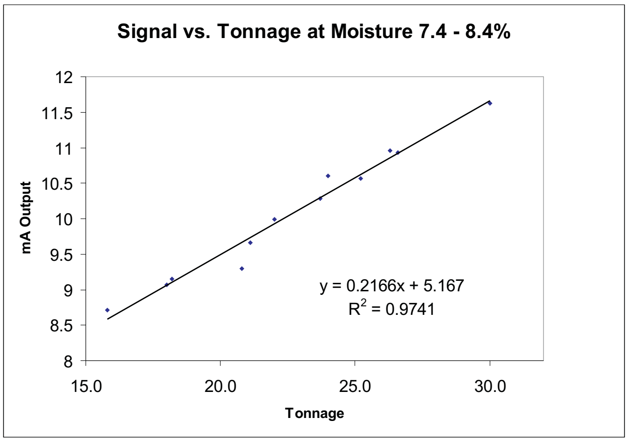


FIG 11 - January 2002 results of Noranda Horne Slag Drag Force input signal dependence on the loading on the belt (tonnage).

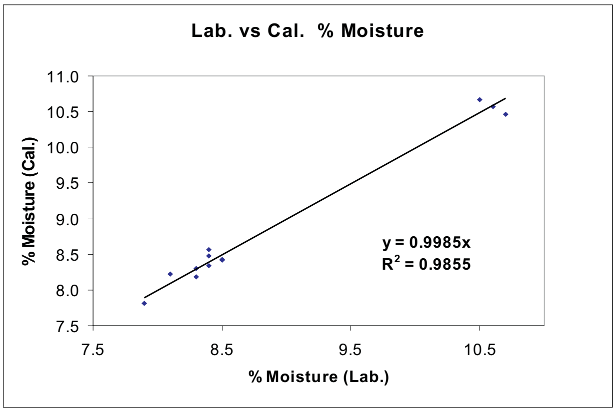


FIG 12 - Noranda Horne results of per cent moisture calculated with tonnage compensation versus per cent moisture of grab samples analysed in the laboratory.

- 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 a key in estimating the presence of water with the drag force principle.
- The Novel Solution of On-Line Moisture utilising the drag force principle demonstrated a promising method for determination of moisture in ore concentrates and other granular materials in the range of five to 15 per cent.
- Calibration models can be found eliminating the affects of varying load and varying particle size for typical solid/liquid separation applications which best described the relationship between drag force and moisture content

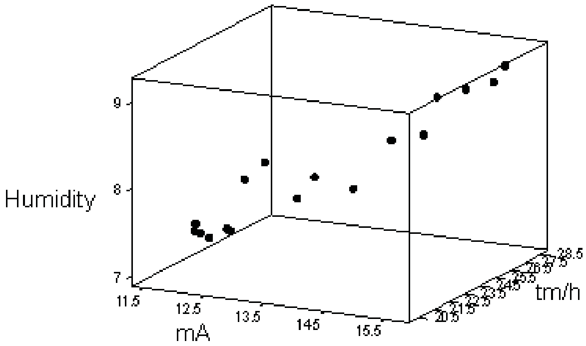


FIG 13 - Noranda Horne-Slag, 3-D plot showing the relationship per cent moisture of grab samples analysed in the laboratory versus the sensor measured drag force (F_d) converted to mA and the belt loading (tonnage).

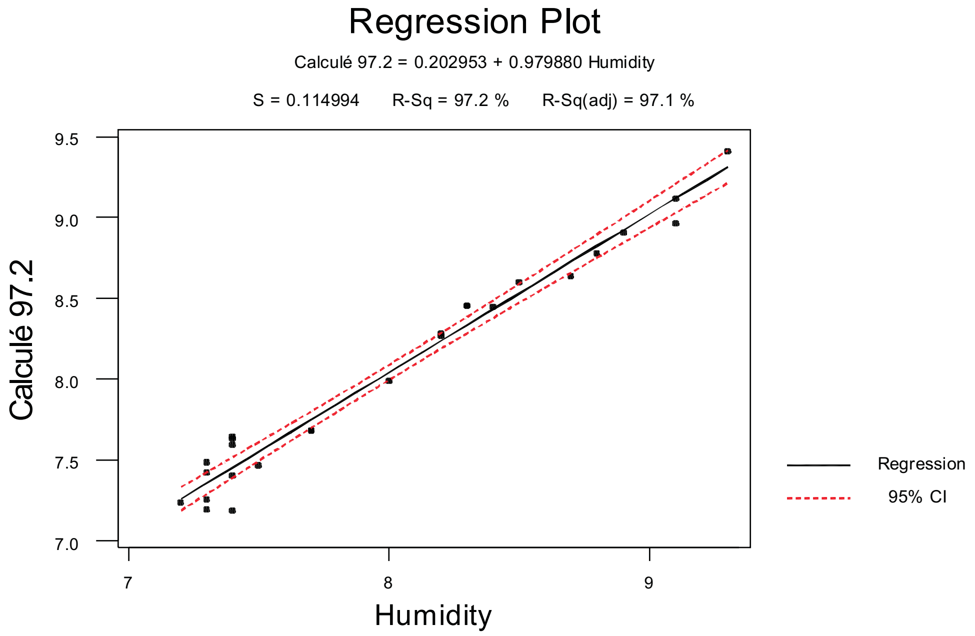


FIG 14 - Noranda Horne-Slag calibration results plot showing the multi-variable squared term model quality where R^2 = 97.2 per cent and S the error of +/- 0.1149 per cent moisture (humidity).

- The test work completed and the commercialisation of the new moisture sensor for continuous and intermittent load concentrate belts will lead to other applications in the area of reducing solid/liquid separation costs an important aim of many processes, ensuring moisture content consistency for material shipments.

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