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On-Line Microwave Moisture Technique Performance of Ferronickel

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Abstract: The competency of observing continuous record of water content or moisture of minerals, then control it in actual real-time basis is crucial that will affects mineral ore quality, cohesivity, process control, material handling and flowability. This paper describes experiment of a Random Stratified Sampling Sweeping Microwave method, moisture content measurement technique that lessen interference, annulling or superimposing signal, that are normal deviations in moisture measurement using microwave transmission method. The technique is used for ferronickel ore running on a belt conveyor exit to the rotary dryer. It showed that high bed depth and high phase stability are essential requirements that must be achieved for successful microwave moisture measurement analysis of ferronickel ore. Attenuation parameter was the suitable parameter for the experiment, instead of Phase parameter, which is common parameter for the ferronickel application. The experimental results revealed accuracy of 0.78wt%, standard error of 0.18 and regression of 0.73.

Keywords: Ferronickel, Microwave Technique, Moisture Content, Real Time.

1. Introduction

Knowing moisture or water content of mineral ore material leads to an important part in the mineral processes, influencing process control, compressibility, material handling, dust suppression, cohesivity, ore quality and flowability. Less or a lot of moisture can alter the quality of the product. Less moisture also reduces yield. Because of that, controlling the suitable moisture content throughout ore production is crucial.

General common methods of moisture measurement cannot determine moisture content in actual or real-time. Mostly, the moisture content is measured by using the weight loss on drying approach, where the sample is heated under specified situations, then the loss of weight is used to determine the moisture or water content of the sample. This method is not suitable for real-time observing of processes because they are destructive, time consuming and invasive. Capacitive sensor (Schimanski, Schroeder, Spitthover, & Moller, 2015), Polarimetric L-Band Microwave Radiometer (PLMR) (Zhang, Jiang, Chai, Zhao, & Wang, 2015), Soil Moisture and Ocean Salinity (SMOS) retrieved soil moisture (Kornelsen & Coulibaly, 2015), Microwave Radiometry (Hassan & Karmakar, 2014), and Dual Probe Heat Pulse (DPHP) (Palaparthy, Lekshmi, Sarik, Baghini, & Singh, 2013) are other measurement techniques used for determining

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moisture content, particularly soil moisture. Additional techniques such as near infrared (NIR) spectroscopy (Zhu, Chang, Wang, Sun, Wang, Wei, Liu, & Zhang, 2014) and nuclear magnetic resonance (NMR) have also been used to observe the moisture content of a sample in real-time. Nonetheless, NMR is often prohibitively expensive, while NIR techniques involve complicated spectra and possess sampling challenges (Corredor, Bu, & Both, 2011). Unwanted motion during processing, such as from vibration device, can negatively affect NIR results. Furthermore, temperature fluctuation during processing can drive to abnormal spectra. From the resemblance of the Standard Error of Calibration (SECs) for both in-situ and off-line output, it is obvious that this limitation is not pose when using microwaves. This is principally a result of three important characters of microwave sensing. First, the wavelength of microwaves is relatively lengthy, particularly compared with infrared waves; this substantially diminishes the impacts of scatter. Second, modern vector network analyzers can accomplish multiple frequency sweeps around the resonant frequency in the same area it took the NIR probes to finish a single scan. A microwave equipment can perform a few hundred complete sweeps in one second. Over the portion of a second that it takes to complete one measurement, the material hardly changes position. For example, at the maximum tangential velocity of 5.1 m/s seen in this research, the powder being calculated would have moved a span of only a few millimeters during a single sweep. Compared to the size of the sensing area, this is very small. Third, microwaves can pass through a material with a distance on the order of centimeters. This penetration helps to substantially diminish wall effects that interfere higher frequency detection schemes. For these reasons, microwave sensors represent an interesting alternative to other established methods, such as NIR analysis (Austin & Harris, 2014).

The real-time measurement of moisture content grants the probability to control moisture addition in the next critical processing stages, for optimum bulk handling. Apart from that, moisture may need to be supervised in order to reduce drying requirements, or to minimize the use of water when the cost of supply is expensive (Miljak, Bennet, Kazzaz, & Cutmore, 2006). In spite of that, there is presently no single method that can supply accurate real-time moisture analysis across the full scope of minerals utilization.

2. Microwave Technique

Research on moisture content measurement in materials utilizing microwaves capability has been carried out for more than 35 years now. Moisture measurement using the microwave capability is based on the relatively high dielectric content of water against the dielectric properties of other materials. When a microwave signal penetrate one material, one portion of the signal is absorbed generating the transmitted amplitude (ie. power level) of the microwave signal to be extremely diminished at the receiver side. A portion of attenuation of this signal is related directly to the dielectric constant of the analysed material. Bluntly, the microwave analysis technique is mainly perpetrated by the stimulation of free moisture molecules instead of the other kind of materials.

Transmission microwave analysis relates the transmission of a microwave beam from one side of the material, and the detection of the phase and amplitude of the beam exiting from the other side of the material. Wave phase, rather than attenuation, is usually the most robust variable for moisture determination (Miljak, Cutmore, Crnoakrak, McEwan & Rowlands, 2001).

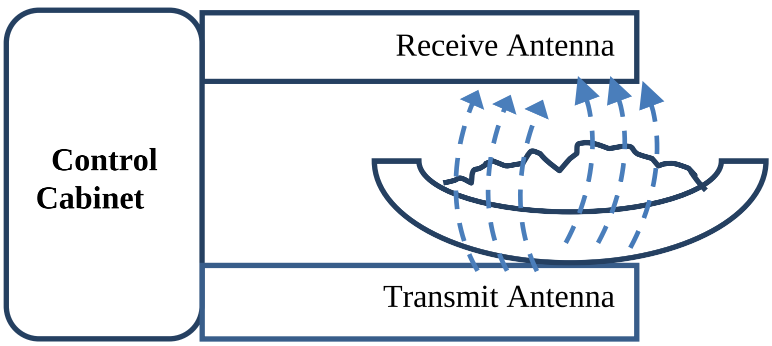

Fig.1 - Microwave Moisture Analyzer.

Diverting this technology into a real-time or on-line situation such as a belt conveyor has posed many defiances, such as interference, alternate path standing wave reflection (SWR) and signal-to-noise ratio (SNR). Perhaps the most substantial advantage of the microwave technology measurement is the basis that it is a transmission technique that measures almost the whole material on the belt conveyor. Optimum antenna design enhances the assessment area while reducing alternate path microwave and severe readings. The microwave measurement technique sequence guarantees that the measurement is in fact continuous and no material within the assessment area goes unmeasured, as shown in figure 1. This is a large advantage compared to many previous surface measurement techniques. Results were steady, loss of the sample is reduced, thus providing instantaneous and reliable information, no human factors during the measurement process are part of the advantages for real-time measurement moisture content applying microwave technology.

At any time that a microwave signal is transmitted into a solid medium (e.g. sample), part of the microwave energy is reflected, some absorbed and some transmitted. The transmitted signal is assessed to determine the amount of certain component in the sample, for example water (moisture content). In spite of that, the reflected signal can impede with the signal that is being transmitted from the transmitting antenna. This interference can take a scheme of annulling or superimposing the transmitted signal. This is unacceptable and a problem that is evident with known microwave moisture analyzer using a single or discrete frequency. By linearly sweeping the transmitted microwave signal, Sweeping Microwave, over a large bandwidth (eg. a range of frequencies) and also sampling the signal using the Random Stratified Sampling technique, errors proposed by signal reflection and superimposing can be decreased. This is the main improvement and novel approach compared to previous methods using discrete frequencies (Palaparthy, Lekshmi, Sarik, Baghini, & Singh, 2013). Random Stratified Sampling is a process of sampling randomly among routine intervals. This is desirable compared to time based sampling because the varying bulk density and depth of material being sampled causes unreliable or unstable periodic effects of signal reflection and superimposition.

The Microwave measurement moisture analyser is constructed to use low level non-ionizing microwave radiation. The microwave power transmitted from the Microwave Moisture Analyser is less than 10 mW (10 dBm). This complies with AS/NZS 4268 which specifies the maximum Equivalent Isotropically Radiated Power (EIRP) for short range radio device. This radiation level exists directly between the two antennas, which in almost all cases is inaccessible due to the conveyor belt. Microwave radiation further than 1 metre from the analyser is virtually undetectable (France, 2007).

The experiment authors conducted for this time was similar experiment with what authors did in (Indra & Hassim, 2016) and (Indra, Aziz & Hassim, 2018), using Random Stratified Sampling Sweeping Microwave method. One of the factor that makes the experiment different was the mineral, the first experiment was nickel ore, as for this second experiment, it’s ferronickel, instead of using nickel ore. Ferronickel is a ferroalloy that consists of approximately 35% nickel and 65% iron. Ferronickel remains stable under normal storage conditions, however when exposed to carbon oxides in reducing atmospheres, there is a risk of forming the toxic gas nickel carbonyl. Another factors that make both experiments were not alike were the ambient temperature, the type of rotary dryer, the speed of belt conveyor, etc. Combination of these unequal factors were the contributors that make both experiments couldn’t be compared one another, although they were using the same microwave measurement technique to find out the moisture content in a real-time basis.

3. Results and Discussion

The Microwave moisture analyzer has been set up on belt conveyor exit to rotary dryer in a ferronickel ore application plant as shown in figure 2, to measure the moisture content on the output from rotary dryer. The purpose of the instrument is to supply a constant real time moisture level of the nickel ore to the dryer control system to allow more accurate adjustment of the drying process. With maximum capacity of 180 t/h, width of belt 900 mm, distance between both axes 233 m, deflection in level 21.7 m, inclination 14.3^0, the bed depth was approximately between 40 mm to 130 mm and the belt speed was set at 60 m/min. The range of moisture is relatively high for this particular application, from 18% to 24% and the size of the materials can go up to 140 mm.

Fig.2 - Application of Microwave moisture analyzer of ferronickel

Just like in any other real-time instrumentations, calibration is a crucial to ensure correct performance. To calibrate the Microwave moisture analyzer one technique named stop belt sampling was employed. In this incident, the raw microwave data was logged over a period of time associating to 15 metres of belt travel before stopping the belt conveyor. The empty belt parameters were determined by logging the system during a period of clean, empty belt and also during a period of normal operation with as much variation in bed depth as possible.

The depth data from the empty belt log files was averaged over a period of 30 minutes. During this time the empty belt depth parameter was calculated to be approximately 49 mm. The Attenuation, Phase and depth data from the varying bed depth log were plotted against each other, allowing the calculation of the empty belt Attenuation and Phase parameters.

The laboratory technique for moisture measurement was weight difference of material before and after oven-drying. In this experiment, a 4 kg aliquot of sample was weighed, dried inside an oven for approximately 48 hours and then re-weighed. Every sample was analysed three times in the laboratory, and no rocks were discarded from the sample. The above methodology was done 20 times and the laboratory sample analysis results regressed against the raw microwave data to acquire the initial parameter calibration.

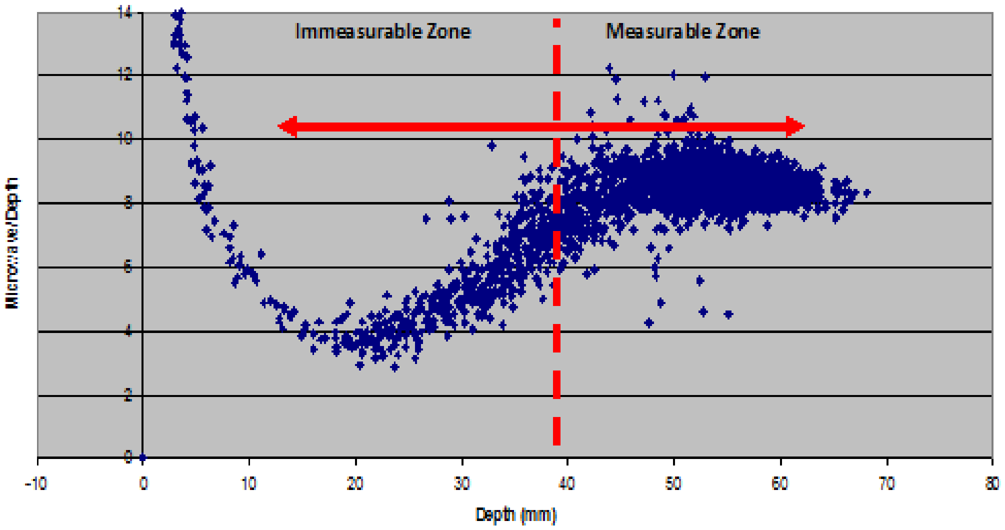

Fig.3 - Plot of raw Microwave (Attenuation) against depth data for empty belt verification (measurable depth range) of the Microwave moisture analyser.

To be able to accurately measure moisture the Microwave (Attenuation)/Depth value need to be linear. From figure 3 above, The empty belt microwave plot was linear above a bed depth of 45 mm, hence the minimum bed depth limit was set to 45 mm. It's called measurable zone for the area on the right (above) 45 mm since Attenuation/Depth gain accurate results. As for the area on the left (below) 45 mm, it is called immeasurable zone since the Attenuation/Depth gives unpredictable results for the area. So, data collected indicated that Attenuation was the most suitable parameter for the measurement of moisture due to limited maximum depth of 90 mm whilst using Phase parameter.

The result obtained from previous work in (Indra & Hassim, 2016), showed that the suitable parameter was Phase rather than Attenuation. The different result between these two very much alike experiments can caused by many factors, like minimum bed depth, variability of the product, type of rotary dryer, ambient temperature, etc. Variability of the product for instance, the sizes of ferronickel ore mineral were generally smaller than the experiment conducted in (Indra & Hassim, 2016), that would lead to thicker minimum bed depth. The different sizes of the same ferronickel ore mineral of the two identical experiments might caused by the different type of rotary dryer each plant used. Each plant has its own finished product specification target, so they might not use the same processes and equipment, such as rotary dryer, belt conveyor speed, etc. These different characteristics that made the two experiments ended up with different outcome, although both experiments used microwave technique to measure moisture content.

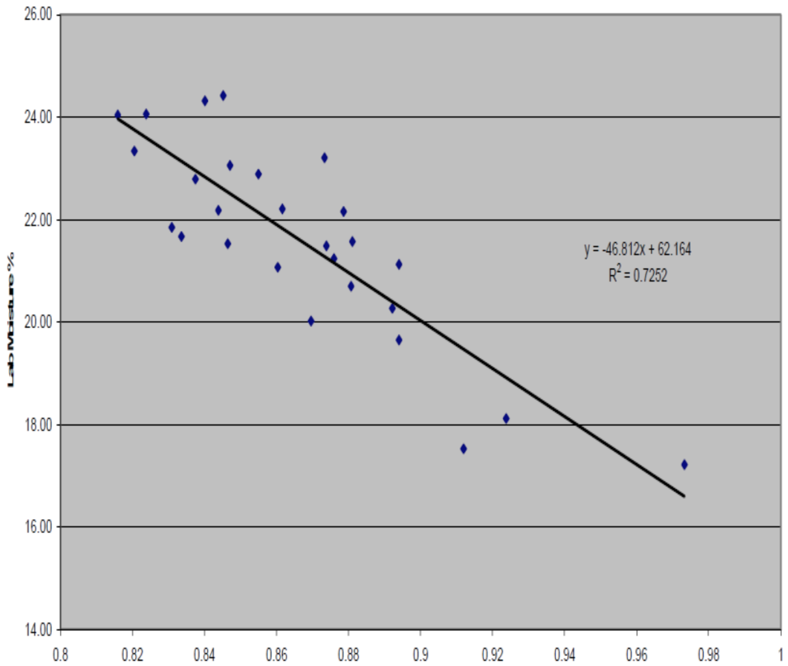

Fig.4 - Plot of Lab (sampled) moisture and Attenuation/Bed Depth, with regression (R^2) = 0.73.

The calibration procedure involved online sampling of the nickel ore. This was achieved by taking a cut of material approximately 300 mm wide across the belt using a shovel whilst the belt was still moving. The samples were taken under 3 conditions set by the drying process, Wet 25% , Normal 21% and Dry 18% (% Estimated moisture results). These three distinct conditions were achieved by changing the Rotary Dyer Temperature to 604.3ºC, 623.2ºC, and 680.5ºC respectively. It took approximately 1 hour for each estimated nickel moisture change until we could do online sampling. Due to the highly variable nature of the moisture in the ore, approximately 10 samples were taken at each condition at between 3 and 5 minutes intervals. This was done so that the average of the samples would give a good indication of the average moisture throughout each sampling condition.

A regression between lab (sampled) moisture and predicted moisture is illustrated in Figure 4. The regression value of 85% shows a satisfactory result that the Microwave moisture analyser can predict the sample moisture successfully. The standard error is 0.18. After taking into account estimates for sampling precision, the underlying analyser accuracy is better than 0.7wt% (Figure 5).

Figure 6 shows a plot of indication trend of moisture waveform output by the Microwave moisture analyzer (cyan color) against Inlet Temperature of Rotary Dryer (fuchsia color), Outlet Temperature of Rotary Dryer (yellow color), and Charge (euro blue color) for a period of one week (7 days).

In general, moisture content indication from Microwave moisture analyzer, has similar reading against actual condition in the field (from Lab samples test), with maximum level of error 1.0%. This level of error is accommodated by consistency of indication in continuous change, a fine tracking between Microwave moisture analyzer and actual condition in the field. The reading of microwave moisture analyzer keeps on changing, and has inverse relation with Inlet Temperature of Rotary Dryer. Outlet Temperature of Rotary Dryer is quite stable.

The two steep valleys, in the middle and at the end of the graph, gave the reading of 0% (zero percent) moisture content, were due to the Rotary Dryer being stopped. And this caused the belt conveyor to stop as well. The average reading for the whole week was 20.30%, the maximum reading was 25.64%, and the minimum one was 10.21%. This abnormal minimum reading was due to the size of material which is below its normal one or caused by inconsistent discharge from the rotary dryer to the conveyor belt . In total, there were 2.31% moisture data reading below 16% for the seven days.

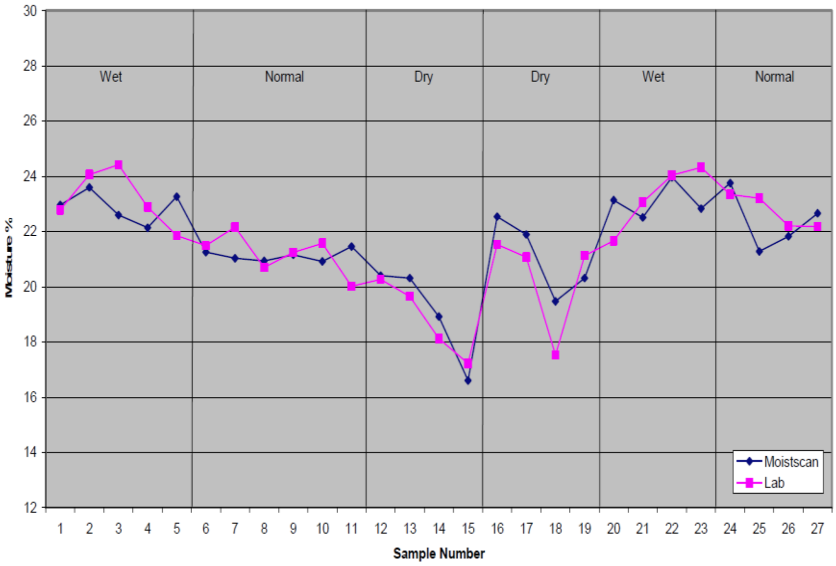

Fig.5 - Tracking plot of Samples moisture and Microwave moisture analyser.

Samples would need to be taken from time to time to verify the correct operation of the Microwave analyser. Other than regular laboratory sample, to check the consistency of Microwave moisture analyzer, the parameter of Inlet Temperature of rotary dryer can also be used, with the assumption that the other parameters remain constant. The Inlet Temperature has an inverse relationship to material moisture content.

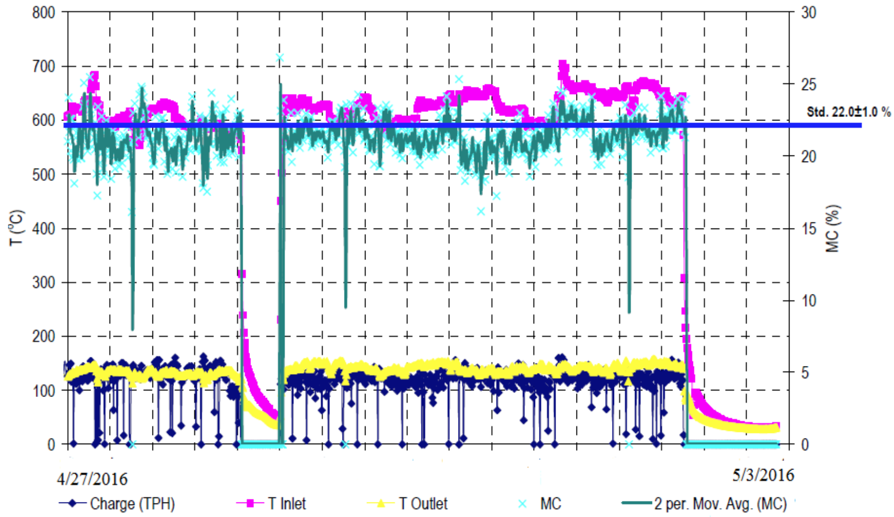

Fig.6 - Moisture waveform output by the Microwave moisture analyzer for 7 days.

As per this paper was prepared, the author has not found any research or report on the other on-line techniques used to measure moisture content for nickel ore. There was a research [7] that compared near infrared (NIR) and microwave resonance (MR) sensor for at-line moisture determination in powders and tablets. It showed that, unlike the NIR method, a general MR method can be used to predict water content in two different types of blends. And MR method can accurately predict water content in bulk powders in the range of 0.6 – 5wt%.

4. Conclusions

The experiments concluded that high phase stability and high bed depth are extremely important requirements that must be met for successful microwave moisture analysis of ferronickel ore. In contrast to the first previous experiment that used Phase parameter to determine the moisture content in nickel ore, the result showed that Attenuation parameter was the appropriate parameter for the experiment. The Microwave analyser successfully utilizes the random stratified sampling sweeping microwave technique in these challenging measurement applications.

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