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# REAL-TIME MICROWAVE MOISTURE MEASUREMENT OF NICKEL ORE IN CONVEYOR APPLICATIONS

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## Abstract

There are many advantages of knowing the moisture content of material in a real-time basis. Moisture content is a crucial parameter that affects material handling. Various technologies have been introduced but only a few were successfully applied for on-line moisture measurement in bulk mineral applications. This paper describes a Random Stratified Sampling Sweeping Microwave technique, moisture content measurement technique that reduce interference, annulling or superimposing signal, which are common errors in moisture measurement using microwave transmission technology. The technique is used for nickel ore running on a belt conveyor exiting the rotary dryer. The experimental results showed regression of 0.85, standard error of 0.18, and accuracy of 0.7wt%.

*Keywords*: Microwaves, moisture, nickel ore

## Abstrak

Terdapat banyak kelebihan apabila mengetahui kandungan lembapan bahan pada setiap masa nyata. Kandungan lembapan adalah parameter penting yang memberi kesan terhadap pengendalian bahan. Pelbagai teknologi telah diperkenalkan tetapi hanya beberapa yang telah berjaya digunakan untuk mengukur lembapan dalam talian terutamanya dalam aplikasi pengendalian mineral pukal. Kertas jurnal ini akan membincangkan teknik pensampelan rawak berstrata menggunakan gelombang mikro sebagai teknik pengukuran kandungan lembapan yang mengurangkan gangguan, pembatalan atau penindihan isyarat, yang menjadi kesilapan lazim apabila menggunakan teknologi penghantaran gelombang mikro untuk mengukur lembapan. Teknik ini digunakan untuk bijih nikel yang sedang bergerak di atas sabuk penyampai setelah keluar dari pengering putar. Keputusan ujikaji menunjukkan regresi adalah sebanyak 0.85, ralat piawai sebanyak 0.18, dan kejituan sebanyak 0.7wt %.

*Kata kunci*: Gelombang mikro, lembapan, bijih nikel



## 1.0 INTRODUCTION

Moisture content of ore material plays a significant role in the mineral industry, affecting ore quality, flowability, dust suppression, cohesivity, compressibility, process control and material handling. Too little or too much moisture can affect the quality of the product. Too little moisture also reduces yield, hence profit. Therefore, maintaining the appropriate moisture content throughout ore production is critical.

Traditional methods cannot measure moisture content in real-time. In most instances, the moisture content is determined using the weight loss on drying technique, where the sample is heated under specified conditions, and the loss of weight is used to calculate the moisture content of the sample. This method is not acceptable for on-line monitoring of processes because they are invasive, destructive, and time consuming. Capacitive sensor [1], Polarimetric L-

Band Microwave Radiometer (PLMR) [2], Soil Moisture and Ocean Salinity (SMOS) retrieved soil moisture [3], Microwave Radiometry [4], and Dual Probe Heat Pulse (DPHP) [5] are additional techniques used for measuring moisture content, particularly soil moisture. Other techniques such as near infrared (NIR) spectroscopy [6] and nuclear magnetic resonance (NMR) have also been used to monitor the moisture content of a sample in real-time. However, NMR is often prohibitively expensive, while NIR techniques involve complicated spectra and possess sampling challenges [7]. Undesired motion during processing, such as from equipment vibration, can adversely affect NIR results. Additionally, temperature variations during processing can lead to abnormal spectra. From the similarity of the Standard Error of Calibration (SECs) for both *in-situ* and off-line results, it is apparent that this limitation is not present when using microwaves. This is primarily a result of three important features of microwave sensing. First, the wavelength of microwaves is relatively long, especially compared with infrared waves; this significantly reduces the effects of scatter. Second, modern vector network analyzers can complete multiple frequency sweeps around the resonant frequency in the same it took the NIR probes to complete a single scan. A microwave instrument can complete several hundred complete sweeps in one second. Over the fraction of a second that it takes to complete one measurement, the material barely changes position. For instance, at the maximum tangential velocity of 5.1 m/s seen in this study, the powder being measured would have moved a distance of only a few millimeters during a single sweep. Compared to the size of the sensing area, this is miniscule. Third, microwaves can penetrate into a material with a distance on the order of centimeters. This penetration helps to significantly reduce wall effects that hinder higher frequency detection schemes. For these reasons, microwave sensors represent an attractive alternative to other established methods, such as NIR analysis [8].

The real-time measurement of moisture content allows the possibility to control moisture addition at later critical processing stages, for optimal bulk handling. Alternatively, moisture may need to be controlled in order to reduce drying requirements, or to minimize the use of water when the cost of supply is expensive [9]. However, there is currently no single technique that can provide accurate on-line moisture analysis across the full range of minerals application.

## 2.0 MICROWAVE MEASUREMENT

Research on moisture content measurement in bulk materials utilizing microwaves technique has been carried out for more than 30 years now. Moisture measurement applying the microwave technique is based on the relatively high dielectric content of water compared to the dielectric properties of other materials. When a microwave signal passes through the material, some of the signal is absorbed causing the transmitted amplitude (ie. power level) of the microwave signal to be significantly reduced at the receiver side. An amount of attenuation of this signal is related directly to the dielectric constant of the measured material. Straightforwardly, the microwave measurement technique is predominantly perpetrated by the excitation of free moisture molecules instead of the other types of materials.

Transmission microwave analysis involves 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 [10].

Shifting this technology into a real-time or on-line condition such as a conveyor belt has raised many challenges, such as standing wave reflection (SWR) and interference, alternate path and signal-to-noise ratio (SNR). Probably the biggest advantage of the microwave technology measurement is the fact that it is a transmission technique that measures approximately the whole material on the conveyor belt. Optimum antenna design extends the measurement area while decreasing alternate path microwave and strenuous readings. The microwave measurement technique sequence ensures that the measurement is in fact continuous and no material within the analysis zone goes unmeasured, as shown in Figure 1. This is a large advantage compared to many previous surface measurement techniques. Results were consistent, loss of the sample is minimized, thus providing instantaneous and reliable information, no human factors during the measurement process are some of the advantages for on-line measurement moisture content using microwave technology.

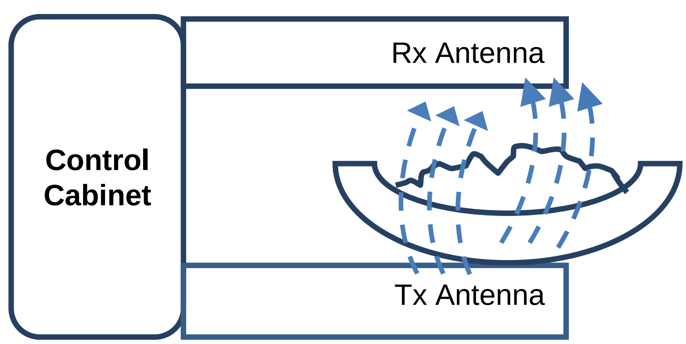


**Figure 1** Block diagram of SM moisture analyzer

When a microwave signal is transmitted into a dense medium (e.g. sample), some of the microwave energy is reflected, some absorbed and some transmitted. The transmitted signal is measured to determine the amount of certain component in the sample, for example water (moisture content).

However, the reflected signal can interfere with the signal that is being transmitted from the transmitting antenna. This interference can take a form of annulling or superimposing the transmitted signal. This is undesirable and a problem that is evident with known microwave moisture analyzer using a single frequency or discrete frequency. By linearly sweeping the transmitted microwave signal, Sweeping Microwave (SM), over a broad bandwidth (eg. a range of frequencies) and also sampling the signal using the Random Stratified Sampling technique, errors introduced by signal reflection and superimposing can be reduced. This is a major improvement and novel approach compared to previous methods using discrete frequencies [5]. Random Stratified Sampling is a process of sampling randomly between regular intervals. This is preferable compared to time based sampling since the varying bulk density and depth of material being sampled causes unpredictable periodic effects of signal reflection and superimposition.

The SM moisture analyser is designed to use low level non-ionizing microwave radiation. The microwave power emitted from the SM 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 equipment. 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 [11].

## 3.0 RESULTS AND DISCUSSION

The SM moisture analyzer has been installed on belt conveyor exit of the rotary dryer in an Indonesian nickel ore application as shown in Figure 2, to measure the moisture of nickel ore and supply moisture data to the plant distributed control system. This measurement is used to improve the drying efficiency and compounded with the tonnage signal from a beltweigher to obtain an accurate amount of weight measurement of dry tonnes feed to the processing plant. With the maximum capacity of 150 t/h, the bed depth was approximately between 20 mm to 50 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 25% and the size of the materials can go up to 150 mm.

**Figure 2** Installation of SM moisture analyzer belt conveyor in nickel ore mining

Just like in any other online instrumentations, calibration is crucial or vital to ensure correct performance. To calibrate the SM 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 was averaged over a period of approximately 20 minutes. During this time the empty belt depth parameter was determined to be approximately 40 mm. This value was adjusted to 30 mm to compensate for the 10 mm of belt sag that occurs when the belt is nominally loaded. 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 case, a 5 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.

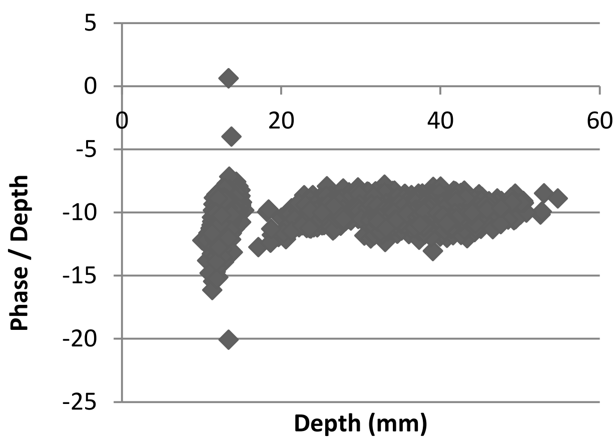


**Figure 3** Plot of phase shift and depth data for empty belt verification (measurable depth range) of the SM moisture analyser

The data collected indicated that Phase was the most suitable parameter for the measurement of moisture due to the relatively low average bed depth. The plot for Phase was linear above a bed depth of approximately 20 mm (Figure 3), hence the minimum bed depth limit was set to 20 mm. It's called measurable zone for the area on the right (above) 20mm since Phase/Depth gain accurate results. As for the area on the left (below) 20 mm, it is called immeasurable zone since the Phase/Depth gives unpredictable results for the area.

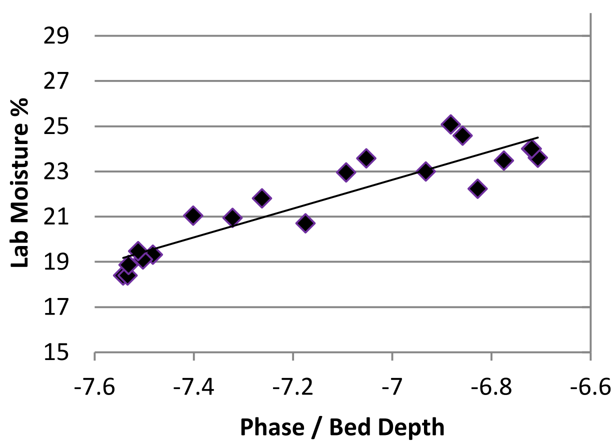


**Figure 4** Plot of Lab (sampled) moisture and phase shift/bed depth, with regression ($R^2$) = 0.85

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 606.5°C, 625.1°C, and 682.5°C 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, samples were taken at each condition at 1 min 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 SM 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 moisture waveform output by the SM moisture analyzer over one week (7 days). The two steep valleys, stated the reading of 0% moisture, 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 21.50%, the maximum reading was 26.84%, and the minimum one was 10.22%. 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 2.41% moisture data reading below 17% for the seven days.

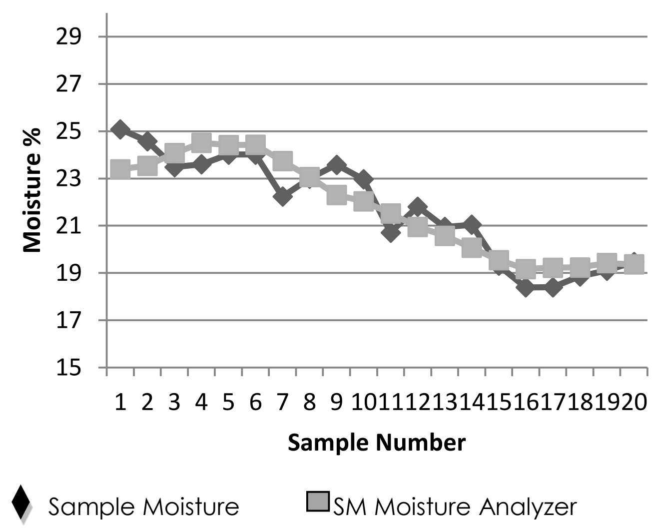


**Figure 5** Tracking plot of Samples moisture and SM moisture analyser

Samples will need to be taken from time to time to verify the correct operation of the SM analyser. Other than regular laboratory sample, to check the consistency of SM 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.

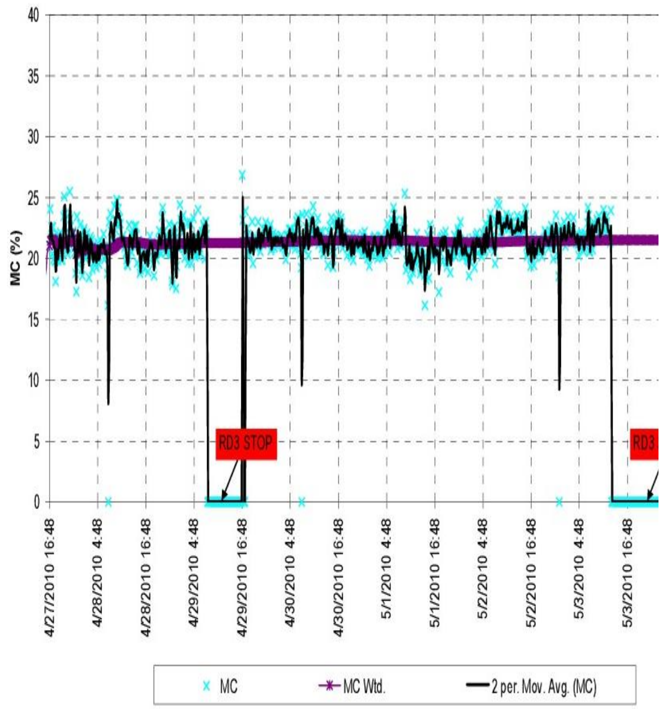


**Figure 6** Moisture waveform output by the SM moisture analyzer over 7 days

So far, the author has not found any research or report on the other real-time 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 0.5 – 5wt%.

## 4.0 CONCLUSION

The results show that high bed depth and high phase stability are essential requirements that must be met for successful microwave moisture analysis of nickel ore. The SM analyser successfully utilizes the random stratified sampling sweeping microwave technique in these challenging measurement applications.

## Acknowledgement

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## References

[1] S. Schimanski, T.F. Schroeder, C. Spitthover, R. Moller. 2015. Contacless Sensor Technology for Measuring Soil Moisture. *IEEE International Conference on Consumer Electronics*. 385-387.

[2] T. Zhang, L. Jiang, L. Chai, T. Zhao, Q. Wang. 2015. Estimating Mixed-Pixel Component Soil Moisture Content Using Biangular Observations From the HiWATER Airborne Passive Microwave Data. *IEEE Transaction On Geoscience And Remote Sensing.* 12(5): 1146-1150.

[3] K. C. Kornelsen, P. Coulibaly. 2015. Design of an Optimal Soil Moisture Monitoring Network Using SMOS Retrieved Soil Moisture. *IEEE Transaction On Geoscience And Remote Sensing.* 53(7): 3950-3959.

[4] M. Hassan, N. C. Karmakar. 2014. Soil Moisture Measurement Using Smart Antennas. *IEEE International Conference on Electrical and Computer Engineering*. 192-195.

[5] V. S. Palaparthy, S. Lekshmi, J. J. S. Sarik, M. S. Baghini, D. N. Singh. 2013. Soil Moisture Measurement System for DPHP Sensors and In Situ Applications. *IEEE International Symposium on Electronic System Design*. 11-15.

[6] C. G. Zhu, J. Chang, P. P. Wang, B. N. Sun, Q. Wang, W. Wei, X. Z. Liu, S.S. Zhang. 2014. Improvement of Measurement Accuracy of Infrared Moisture Meter by Considering the Impact of Moisture Inside Optical Components. *IEEE Sensors Journal.* 14(3): 920-925.

[7] C. C. Corredor, D. S. Bu, and D. Both. 2011. Comparison Of Near Infrared And Microwave Resonance Sensors For At-Line Moisture Determination In Powders And Tablets. *Anal. Chem. Acta*. 696(1-2): 84-93.

[8] J. Austin, M. T. Harris. 2014. In-Situ Monitoring of the Bulk Density and the Moisture Content of Rapidly Flowing Particulates Using a Microwave Resonance Sensor. *IEEE Sensors Journal.* 14(3).

[9] D. G. Miljak, D. Bennet, T. Kazzaz, N. G. Cutmore. 2006. On-Line Microwave Moisture Measurement of Iron Ore and Mineral Concentrates in Conveyor Application. Presented *at the Instrumentation & Measurement Technology Conference (IMTC)* Sorrento, Italy.

[10] D. G. Miljak, N. G. Cutmore, D. Crnoakrak, A. J. McEwan and T. Rowlands. 2001. Low Frequency On-Line Microwave Moisture Analyser For The Minerals And Process Industries. *Proceedings 4th Conference On Electromagnetic Wave Interaction With Water And Mosit Substances, Weimar, Germany*. Kupfer K. (ed.). 301-307.

[11] G. G. France. 2007. Analysis of Variable-Depth Sample Using a Sweeping Microwave Signal. *U.S. Patent* 7,190,176 B2, March 13, 2007.