EVALUATION OF THE LOW FREQUENCY MICROWAVE (LFM) MOISTURE ANALYSER FOR SINTER PLANTS

低频微波水分分析仪在烧结工厂中应用的评价

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Abstract Improving moisture control to achieve the optimum moisture for a sinter blend can lead to significant improvements in sinter plant productivity and quality. The Low Frequency Microwave (LFM) moisture analyser developed by CSIRO and commercialised by Intalysis has been successfully used in BHP Billiton's iron ore mines for on-line moisture measurement to control water addition to improve the dust and handling properties of its iron ores. Laboratory tests have now been carried out to evaluate the LFM's capability with a range of sinter plant blends. The standard error accuracy for individual blends was on average ±0.2%H_2O. Significantly different ore blends require individual calibrations (especially with concentrates). Return fines level, burnt lime rate and coke rate can also influence the moisture measurement but if necessary can be automatically compensated for in the LFM to improve the accuracy.

Keywords LFM, microwave moisture analyser, iron ore, sinter, granulation

摘要
改进水分控制以获得烧结混合料的最优水分能够极大的改进烧结的效率与品质。澳大利亚联邦科学与工业研究组织（CSIRO）研制开发了一种低频微波水分分析仪。这一分析仪经由Intalysis公司商业化后已经在BHP Billiton的铁矿石产区已经取得了成功的应用。通过在线测量物料水分含量，低频微波水分分析仪可以用来实现精确的水分控制。精确的水分控制一方面有助于减少灰尘的排放量，另外一方面有助于防止物料粘结。BHP Billiton近期开展了低频微波水分分析仪对烧结混合物料的水分测量能力的研究。实验结果表明对单一烧结混合物料，低频微波水分分析仪的平均标准误差为±0.2%.
实验结果同时显示低频微波水分分析仪需要针对不同的烧结混合物使用不同的标定模型。特别的，回收精细粉水平，燃媒比例与焦炭比例均对水分测量产生影响。自动补偿方可以消除这些影响从而提高低频微波水分分析仪的测量能力。

关键词 LFM，微波水分分析仪，铁矿石，烧结， 粒化

1. Introduction

During iron ore sintering, mix moisture has a significant impact on sinter plant productivity and quality. Granulation which is the first step in sintering is controlled by moisture. The degree of granulation of the green feed mix determines the permeability of the sinter bed. As shown in Figure 1(a), the maximum permeability for different ores occurs at different optimum moistures and depends on the ore porosity and particle size distribution[1]. Once sintering commences, convective heat transfer which is strongly dependent on bed permeability and gas flow drives the flame front down through the bed. The flame front speed sets the burn-through point and therefore the strand speed and sinter productivity. If the flame front speed is too fast, this can reduce the time that the mix is above melting temperatures and effect the sinter strength and size. An example of this from sintering tests is shown in Figure 1(b) where at the higher moistures, the sintering time decreased (i.e. flame front speed was faster) but the sinter strength and yield deteriorated. Therefore, at the sinter plant it is important to determine

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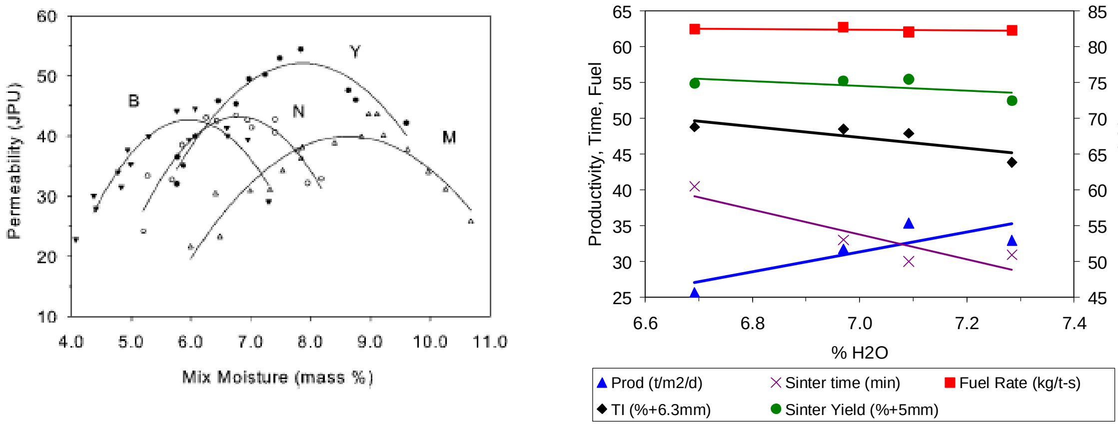
the optimum moisture for each ore blend and improve the moisture control at this optimum. With improved moisture control and more stable operation, sinter plants have reported productivity increases of up to 5% while maintaining or improving sinter quality [2,3,4].



(a) Permeability of different ores (b) Sinter productivity and quality

Figure 1. Effect of moisture on granule permeability and sinter productivity and quality.

Online analysis is essential for improved moisture control and a number of technologies have been used with varying degrees of success. Conductivity and capacitive methods have accuracy limitations and require physical contact with the mix moving on the conveyor belt. Nuclear methods are expensive, have significant Occupational Health and Safety management issues requiring extensive regulatory control and may be effected by the water of crystallisation in goethitic ores. Near Infra Red methods measure only the surface moisture of the mix and are subject to reflectance level issues associated with changes in bed height and grading. Since 2002, BHP Billiton (BHPB) has had considerable success implementing the Low Frequency Microwave (LFM) moisture analyser for online moisture measurement in its iron ore operations (over 20 units now installed). This has minimised the dust and improved the handling properties of its iron ore products. Another consequence of this initiative is delivering a better quality product with a more consistent moisture that is a more stable feed to customer steel plants. BHPB therefore also became interested in the capability of the LFM for improving moisture control in sinter plants using their iron ores. Laboratory tests have been carried out at BHPB Newcastle Technology Centre (NTC) with Intalysis to evaluate the LFM performance on a range of sinter plant blends. The findings are reported here.

2. LFM Moisture Analyser

The LFM was developed by the CSIRO, Australia's largest research organisation which has over 20 years experience in microwave moisture analysis, and subsequently commercialised by Intalysis. It is used in continuous, on-conveyor applications ranging from conventional materials to highly attenuating materials such as iron ore, minerals concentrates and high moisture coals.

The technology is based on a system where microwaves are transmitted through the material from above and received below the belt as shown in Figure 2. When microwaves pass through moist materials they slow down (and hence change phase) and weaken (attenuate) as the energy is transferred to the material. The LFM measures the microwave phase shift and attenuation to determine the moisture content of the material. Due to the integration of the LFM with a belt weigher, moisture measurements are not affected by vertical segregation of the material on the belt, are independent of the material size and belt speed and are effective with both fabric and steel cord belts. The LFM installs directly on the conveyor belt requiring little or no modification of the existing structures. The system comprises low profile antennas and a compact industrial instrument enclosure. The analyser does not contact the material monitored nor does it interfere with the routine operation of the conveyor. Once installed and calibrated the analyser operates continuously without the need for sampling.

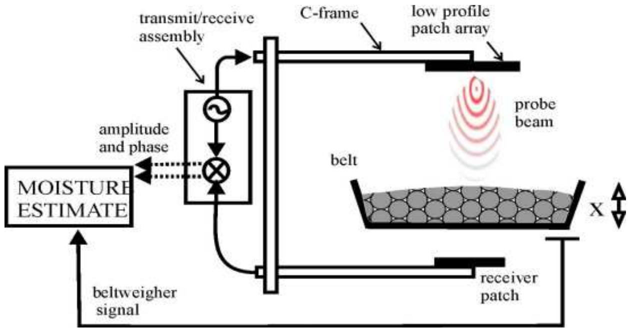


Figure 2. Diagram of LFM.

Key design features of the LFM include:

- True continuous moisture measurement
- Through material analysis which is inherently more accurate than surface measurement
- Very safe with very low power emitted (<1 microwatt/cm^2 at the antenna)
- Rugged, light-weight, low profile microwave antennas for easy installation
- Large dynamic range for measurement of high moisture content, thick beds or highly attenuating materials
- High performance low frequency microwave electronics provide exceptional accuracy
- Inexpensive field maintenance due to easily replaceable modular electronics
- Direct output to plant with industry standard 4-20mA loop and serial or Ethernet interfaces.

The LFM has already proven successful in trials at an Outokumpu chromite pelletising plant in Tornio, Finland. During moisture sampling trials over 6 months, the LFM had an accuracy of ±0.08%H_2O (one standard deviation). This high accuracy was assisted by a high accuracy oven moisture sampling program (±0.02%H_2O) and a very stable ore feed to the plant.

3. Test Procedure

The laboratory tests conducted at NTC evaluated the capability of the LFM for measuring the moisture of sinter granule mixes. Each test mix consisted of a specified blend of iron ores, coke breeze, limestone, serpentine, dolomite, recycle waste materials (BF flue dust, mill-scales, etc.), burnt lime and return fines typical of sinter plant operations. Approximately 85 kg of material was pre-mixed then granulated with water in a pilot-scale 1.1m diameter granulation drum to target moistures of 5.0%, 6.0%, 6.5%, 7.0% and 8.0%H_2O. At each moisture the mix was loaded into a plastic container with a fabric cord conveyor belt placed in the bottom. The sample was positioned between the transmitter and receiver microwave antennas (type S) as shown in Figure 2 and Figure 3. LFM microwave attenuation and phase change were measured. This was repeated for 4 bed depths from approximately 230mm down to 20 mm. The test program listed in Table 1 was designed to evaluate the sensitivity of the LFM to the following sinter blend variables that might change the dielectric properties of the blend and effect the moisture measurement: ore blend, % return fines, % coke breeze, % burnt lime, % recycle materials and temperature.

Table 1. Test program design (including ore blends) and LFM accuracy results.

Group	Test	Ore Blend (*)	Return Fines	Coke	Burnt Lime	Recycle Material	Temp.	Accuracy Std Error
1	L4	J	15	4	0	2		0.11
	L2	J	20	4	0	2		0.22
	L3	J	25	4	0	2		0.18
2	L6	J	20	3	0	2		0.14
	L2	J	20	4	0	2		0.22
	L5	J	20	5	0	2		0.21
3	L2	J	20	4	0	2		0.22
	L9	J	20	4	0	4		0.13
4	L2	J	20	4	0	2		0.22
	L11	J	20	4	2	2		0.27
	L12	J	20	4	4	2		0.13
5	L2	J	20	4	0	2		0.22
	L13	C2	20	4	0	2		0.13
	L7	C	20	4	0	2		0.29
Temp.	L10	J	20	4	0	2	92C to14C	

** Base blend (L2): 62% ore, 4% coke, 8% limestone, 2% serpentine, 2% dolomite, 2% waste recycle materials, 0% burnt lime, 20% return fines.

* Ore Blend (% dry ore basis)	J	C2	C
Newman High Grade Fines	10	40	30
MAC Fines	10	20	20
Yandi Fines	40	10	10
Australian hematite fines	10	0	0
Brazilian hematite fines	30	30	20
Hematite concentrate	0	0	10
Magnetite concentrate	0	0	10
Total	100	100	100

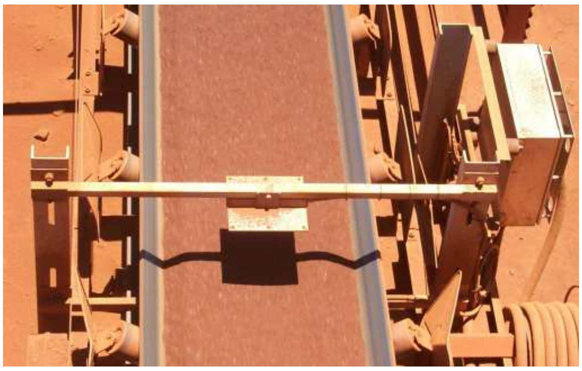
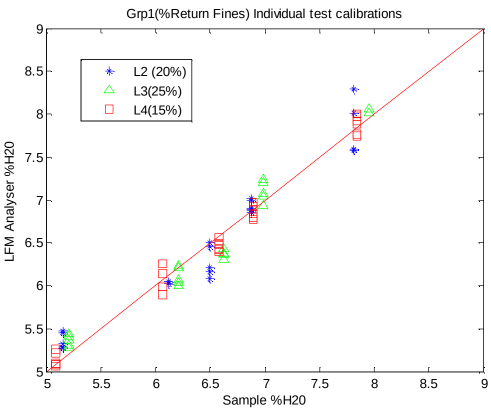


Figure 3 LFM operating at BHPB Iron Ore mine and in NTC granulation laboratory.

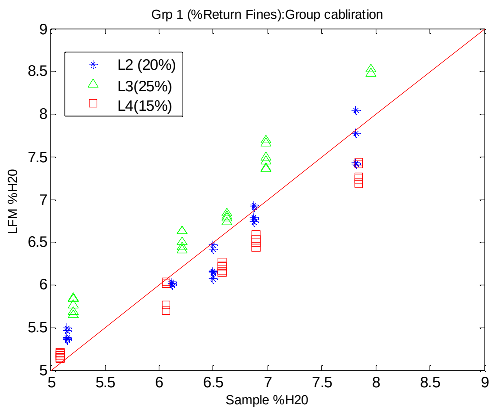
4. Test Results

The laboratory tests showed that the LFM was able to measure the moisture of a wide range of sinter blends tested. The microwave phase change increased as the moisture and the mass of material increased. Calibrations for each test were obtained by building a correlation between the oven drying moisture and the microwave phase changes and material mass. Figure 4(a) shows the comparison of LFM moistures and oven drying moistures for group 1 blends with different return fines levels (15%, 20% and 25%). Moistures varied between 5% and 8%H_2O, and bed depth varied from 20 to 230mm. The accuracy (one standard deviation) varied between 0.11% and 0.22%H_2O for these three blends (see Table 1). Figure 4(b) shows the same comparison if a group calibration was used for all return fines tests. A 5% increase in return fines led to an apparent 0.35%H_2O increase in the LFM moisture reading. In a sinter plant it would be possible to add a multi-variables compensation package to the LFM software to adjust for this return fines effect.

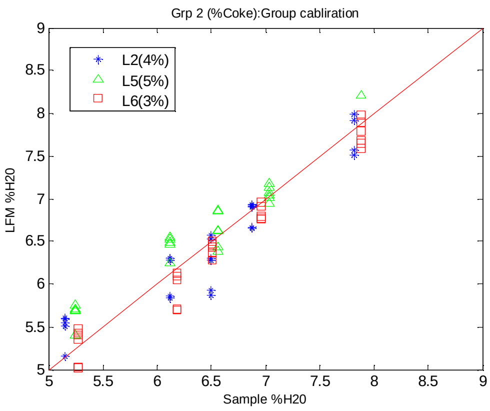
There were concerns that coke which is a highly attenuating material might have a negative effect on the LFM measurement. However this was not the case. Figure 4(c) shows that for a wide range of coke blends (3% to 5%) the LFM had good accuracy (0.14% to 0.22%H_2O). The coke level had much less of an effect on the LFM measurement compared to the return fines. It is thought that the mixing and dispersion of the coke in the granules prevented it from becoming a continuous phase in the bed thus avoiding excessive attenuation. Similarly, the recycle waste materials (tested in group 3) were well dispersed throughout the granules and the LFM measurement did not appear to be sensitive to their level (accuracy 0.13% to 0.22%H_2O).



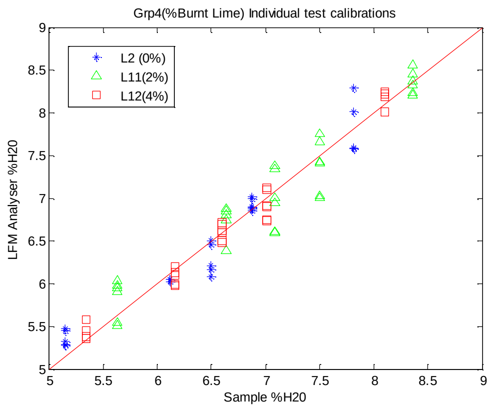
(a) Return fines, Individual test calibrations



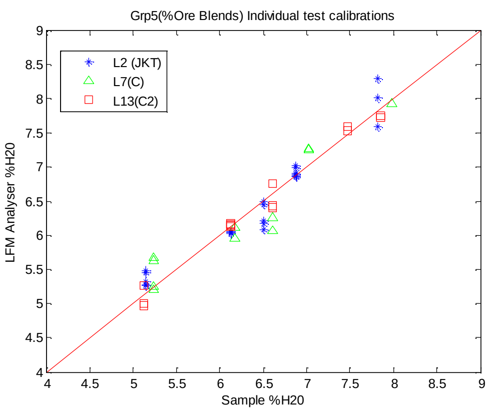
(b) Return fines, Group calibration



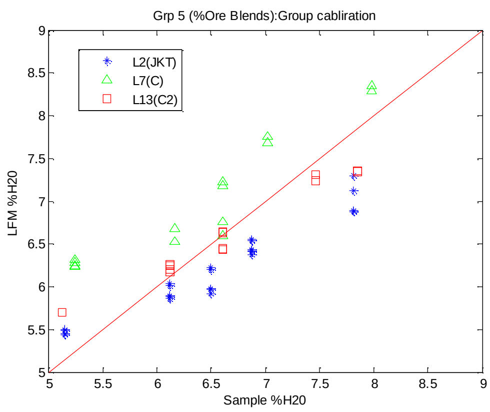
(c) Varying coke, group calibration



(d) Varying burnt lime



(e) Different ore blends, individual calibration



(f) Different ore blends, group calibration

Figure 4. Comparison of LFM and oven drying moistures for each sinter blend group.

In the group 4 blends, the burnt lime level was varied between 0% and 4%. Extra water was added in the granulation drum for the reaction that forms hydrated lime [$Ca(OH)_2$]. In the 4% burnt lime test, the granules heated up from 15°C to 38°C during granulation because of the rapid exothermic reaction. The granule bed started to cool during the initial LFM measurements indicating that the hydration reaction had finished. A comparison of the LFM moisture and oven drying moisture for the burnt lime tests is shown in Figure 4(d). The standard error accuracy varied from 0.13% to 0.27%H_2O. A group calibration comparison indicated that a 1% increase in burnt lime led to an apparent 0.15%H_2O decrease in the LFM moisture reading. In a sinter plant, compensating for the burnt lime rate is likely to improve the LFM accuracy. A separate test in which dried granules were heated in an oven to 92°C then repeatedly measured with the LFM as they cooled to 14°C showed minimal effect on the phase change and attenuation. However it should be noted that the granules were dry to avoid changes in moisture during this temperature test.

Iron ores can have different dielectric properties. In general microwave attenuation increases in the following order: Channel Iron Deposit (CID, Yandi) < Marra Mamba < Brockman hematite < Brazilian specular hematite < magnetite concentrate. Therefore LFM tests were carried out with different iron ore blends (J, C2 and C) as listed in Table 1. A comparison of LFM and oven drying moistures is shown in Figure 4(e). Standard error accuracy varied from 0.13% to 0.29%H_2O. However Figure 4(f) shows that LFM accuracy was not as good if a single group calibration was used for all the ore blends. Blend J consisted of mainly Yandi CID and Brazilian hematite plus Newman and MAC fines. Blend C2 consisted of less Yandi and more Newman and MAC fines. Blend C included 10% hematite concentrate and 10% magnetite concentrate and was more difficult to measure. As the blend changed from J to C2 to C the microwave phase shift increased leading to higher LFM apparent moistures. Also the attenuation increased leading to lower maximum bed depths on the conveyor belt that could be measured by the LFM (approximately 200, 150 and 110mm for blends J, C2 and C respectively). LFM accuracy on the sinter plant will improve if different calibrations are used for significantly different ore blends.

5. Conclusion

Different iron ore sinter blends have different optimum moistures for granulation and permeability. Improving moisture control to achieve the optimum moisture can lead to significant improvements in sinter plant productivity and quality. The Low Frequency Microwave (LFM) moisture analyser developed by CSIRO has been successfully used in BHP Billiton's iron ore mines for on-line moisture measurement since 2002. Laboratory tests reported here show that the LFM also has the capability to measure the moisture of a wide range of sinter plant blends online. The standard error accuracy for individual blends with moistures ranging from 5% to 8%H_2O was on average ±0.2%H_2O. Individual calibrations are required for significantly different ore blends (especially those involving more highly attenuating concentrates). Maximum measurable bed depths on the conveyor varied from 200 to 110mm depending on the microwave attenuation properties of the blend. Return fines level and burnt lime rate and to a lesser extent coke rate can also influence the moisture measurement. If necessary these can be automatically compensated for in the LFM to improve the accuracy.

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