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Aeration Induced Moisture Reduction of Iron Ore

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ABSTRACT

Mining is increasingly occurring near or below the water table. This has led to a higher rate of handling problems associated with increased moisture and increased adhesion which lead to higher rate of blockage events within the materials handling chain. Typically, these ores and minerals are known as 'Wet and Sticky Materials'.

Currently there is very limited knowledge and/or methodologies for effective design of efficient materials handling systems when it comes to handling these wet and sticky materials. However, there is one major parameter which significantly affects handleability of a wet and sticky ore, namely its moisture content. Flow property testing has shown that when moisture is reduced, the adhesive properties of the ore are also significantly reduced, thereby increasing ore flowability.

The research embodied in this paper investigated the moisture reduction rate through a loose packed bed of iron ore using dry, ambient temperature airflow. A comparison of the predictive capabilities of a proposed drying model to data obtained from onsite experiments using iron ore fines is made. Building on an assumption made by Hukill (1954), a second term has been proposed to account for rewetting effects in the drying process. From this research, identification of improved moisture reduction approaches is envisaged.

INTRODUCTION

As the result of global economic climate shifts in recent years, mineral and ore mining is increasingly occurring near or below the water table.

The increase in excess water production over the last 18 years is very noticeable. This has led to a higher rate of handling problems associated with less attractive deposits. In particular, the increasing occurrences of 'wet and sticky' materials have led to a higher rate of blockage events within the materials handling chain. The reason for blockages occurring is that the geometries of the materials handling elements, like chutes, hoppers and storage silos, are designed based on one set of material characteristics. As the material moves away from this initial design condition towards a more adhesive state, the geometry it encounters allows it to build up and prevent flow through that system i.e. forming a blockage, which may be due to shallow wall angles or too narrow discharge openings.

Currently there is very limited knowledge and/or methodologies that allow for the design of efficient materials handling systems when it comes to handling these wet and sticky materials. Moreover, the modification of existing systems to suit new material types may not be a viable solution. Therefore, being able to alter the characteristics of the bulk material, moving it into a more manageable flow state, is one way in which the handling of such materials could be improved.

The 'Handleability index' (see Iron Ore 2017, paper number 71), is a new method to characterise the flowability of a bulk material. It is an identification parameter which has a scale, from 0 to 1, 0 exhibiting high adhesion and therefore severely problematic and 1 being free flowing. Flow property testing (Figure 1) has shown that one identifiable parameter which significantly affects Handleability of wet and sticky ore is its moisture content. It can be seen that when moisture is reduced, with respect to unsaturated material handling systems, the adhesive properties of the ore are also significantly reduced, thereby increasing ore flowability.

If the current trend in excess water production is followed in coming years and decades, then new dewatering solutions must be developed today to eliminate or minimise adhesive based handling problems of the future.

In this paper laboratory scale air induced drying results for ores of known properties, using a cylindrical packed-bed drying rig, are examined in order to validate a proposed drying model.

AIR INDUCED MOISTURE REDUCTION SYSTEMS

Here an air induced moisture reduction (AIMR) system, as the name suggests, is any drying method that forces air through a bulk material in an effort to reduce the moisture content (MC) of the bulk material. By controlling the parameters of the input air to the system, such as temperature and flow rate, optimum drying characteristics can be achieved for a given set of output parameters, such as the residence time (the amount of time the bulk material is held in the system) and required moisture content reduction.

Air is a readily available resource for use throughout a processing plant. In this regard, being able to use this resource economically has its obvious benefits. The scope for development in this area can be seen when comparing the cost verses the drying capacity for three different categories of dewatering equipment. These being Sedimentation, Mechanical Dewatering and Thermal Drying.

The relatively large cost per tonne for current thermal drying systems is an indication of the improvement opportunity that may be realised by an AIMR system. It is important to note that this paper does not claim that AIMR systems may provide a blanket solution to dewatering problems, rather it contributes as one key part in a total dewatering solution.

In order to analyse the drying behaviour of iron ore samples, a test system was built. Figure 2 is an annotated picture of the experimental set-up of the AIMR rig used for testing. The purpose of this piece of equipment is to provide quantitative data on the drying behaviour of iron ore for various combinations of input air temperature, air flow rate, bed depth and initial moisture content. Note that the system is exposed to atmosphere via an open top to allow for the escape of moisture.

FACTORS INFLUENCING THE DRYING RATE OF AN AIMR SYSTEM

The performance of the total system is known to be impacted by a wide variety of variables that describe the input parameters and material characteristics. The objective of the work presented in this paper was to identify the key factors required to predict the drying performance of a given AIMR system.

Below lists some of the variables that may need to be considered in the analysis of AIMR systems.

- Volume Flow Rate of air $\forall$
- Input Temperature T
- Void Ratio VR
- Volume V
- Bed Height h
- Permeability ε
- Bulk Density ρ_b
- Moisture Content MC
- Heat capacity C_p

MODELLING THE DRYING BEHAVIOUR

Previous research found on deep bed drying, for example those described in Beke. J, Gal. G. Z (1994), were found to be limited in their applicability to a narrow band of relatively low air flow rates and/or air temperatures. The work of Hukill was noted, where the assumed process of deep bed drying could be described by the following equation.

$$\frac{X - X_e}{X_1 - X_e} = e^{-k \cdot \tau} \tag{1}$$

Where:

k	is the drying coefficient.
τ	is the residence time of drying.
X	is the temporary moisture content on a dry basis (kg/kg).
X_e	is the equilibrium moisture content on a dry basis (kg/kg).
X_1	is the initial moisture content on a dry basis (kg/kg).

Models of this general form, as proposed by Hukill (1954) for deep bed drying, are relatively simple to compute and appropriate for approximations of the drying behaviour. However, the rewetting effect is not considered in a model of this form. Rewetting refers to the ability of a material undergoing a drying process to absorb moisture from its surrounding environment. This moisture may come from the input air or humidity in the surrounding environment. With this in mind the following generalised model has been proposed to describe the drying behaviour.

$$M(t) = M_0 e^{-k_1 t} + M_{wet\ air}(1 - e^{-k_2 t}) \tag{2}$$

Where:

$M(t)$	is the mass of moisture remaining in the sample in kg.
M_0	is the original moisture mass available to be lost in kg.
$M_{wet\ air}$	is the input moisture from humid air supply in kg.

k_1	is the '*k*-factor' for drying.
k_2	is the '*k*-factor' for re-wetting.
t	is the residence time of material in the aeration unit.

The new model suggested in Equation 2 can be seen to be an extension on Hukill's assumption. The *k* factors are the only unknowns, to be used to fit predictive models to experimental data.

It will be appropriate to assume, for the initial onsite experimental system used, that the supply air would be a dry air input. Therefore, the k_2 factor is equal to zero and the equilibrium moisture content for all testing would be zero. This assumption of a negligible rewetting effect may also apply to experiments using shallow material beds. Since the experimental set-up used in this research utilises an unconfined material bed in an unsealed aeration unit, the residence time of the air through the material (different from the variable '*t*' listed above) is small for shallow beds, therefore any rewetting behaviour will have negligible effect.

EXPERIMENTAL RESULTS

For the analysis within this paper, initial testing has been conducted in order to demonstrate the predictive capabilities of the proposed drying model as applied to iron ore fines. The bulk material tested in this analysis was limited to particle sizes below 10mm.

In Figure 3, the top pictures (a1, b1 and c1) show the initial state of the samples prior to air flow for each bed height. The bottom row (a2, b2 and c2) shows the significant channelling effect occurring once air flow is introduced to the sample. Given the difficulties accounting for the channelling effect, it was deemed appropriate to remove the fines in the samples in order to achieve a more even distribution of the drying air throughout the entire cross-section of the bed. Accounting for the channelling affect is to be the subject of future work in this project.

Figure 4 (a and b) show the results for an experiment run at ambient air temperature (23°C) with a flow rate of 0.2 m^3/min. The initial material mass was 17.3kg, with 21.8%MC and the dry mass was 14.2kg, with 0%MC. The bed height was constant at 145mm. The data was discretised and the corresponding error bars are shown.

Using the final and initial conditions data from the experiment the model was able to be created. The goodness of fit is largely dependent on the value of the *k* factors since the initial and final conditions are relatively straight forward to measure with a high degree of accuracy. A k_1 value of 0.003 was found to provide the best fit to the data. Future work will endeavour to include material and system properties into a calculation for the *k* factors. For specific applications it could be argued that the k value could be altered to provide a closer fit for the faster loss rate section of the drying period. This may be preferential since for most iron ore drying would not need to achieve moisture contents of below 6%. Therefore, sacrificing accuracy at the dry end of the prediction curve could be feasible in order to achieve a higher accuracy in the moist end of the prediction curve. However, the scale at which the accuracy would change may be negligible for the majority of bulk materials applications.

The results indicate that the model has good predictive capability for Iron Ore drying. This is evident in the close fit that the model holds over the entire measurement period.

CONCLUSIONS

This paper compared the predictive capabilities of a proposed drying model to data obtained from onsite experiments using Iron Ore.

From the results using the larger particle samples, it was seen that the drying model can provide a good approximation to the drying rate with proper management of the *k* factors. In this case a k_1 value of 0.003 was found to provide the best fit to the data.

Future work will endeavour to include material and system properties into a calculation for the *k* factors, management of the rewetting phenomenon as well as methods to account for the channelling effect in deep bed drying.

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FIGURES

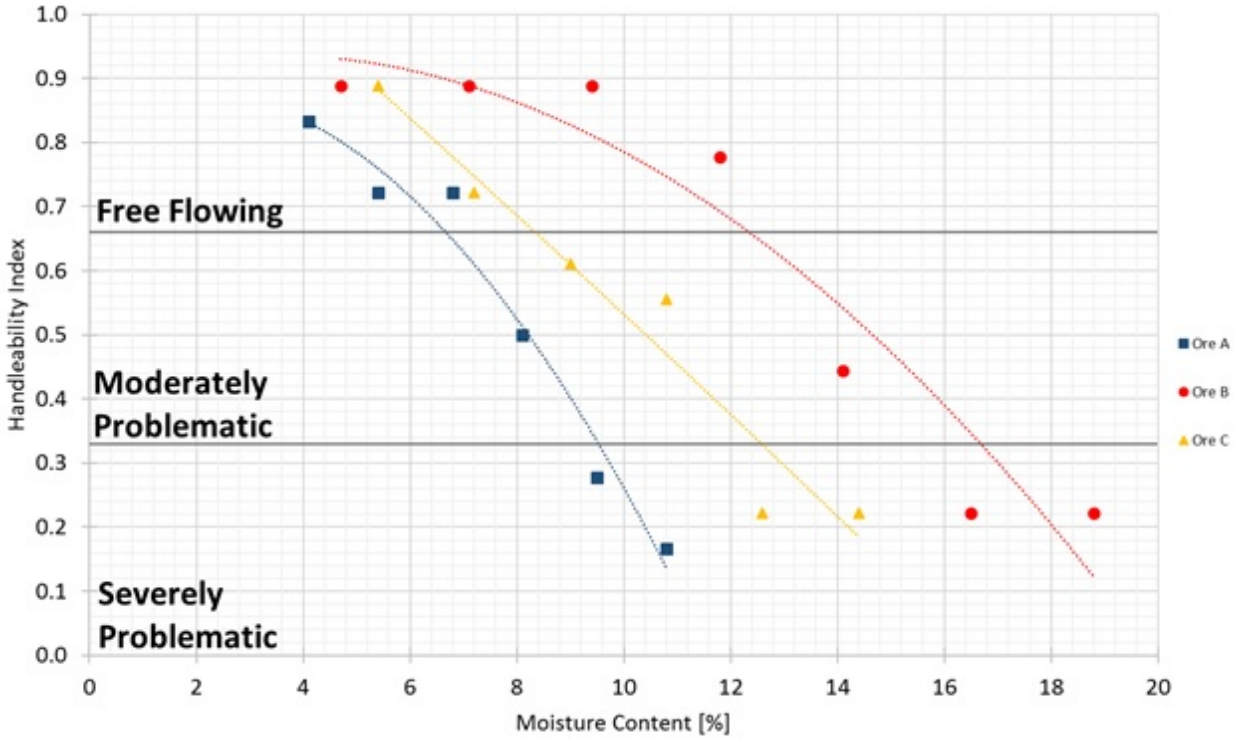

Figure 1 – A Handleability index comparison shows the increasing flowability when moisture content is decreased. Taken from paper 71, Iron Ore 2017.

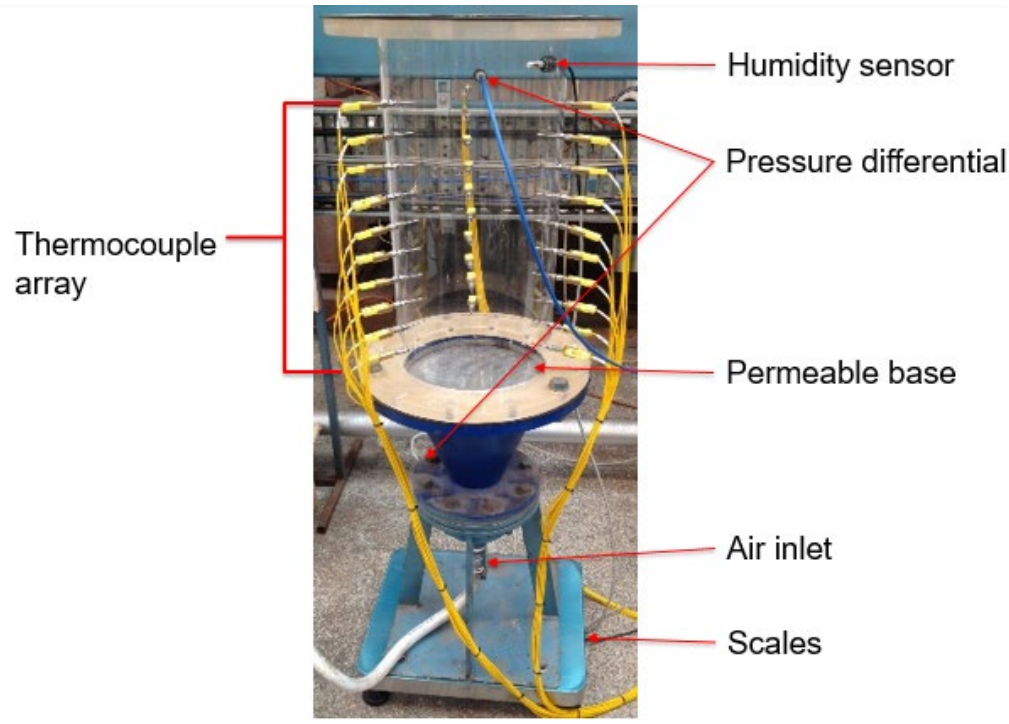

Figure 2 – Annotated picture of the experimental AIMR rig used for testing in this paper.

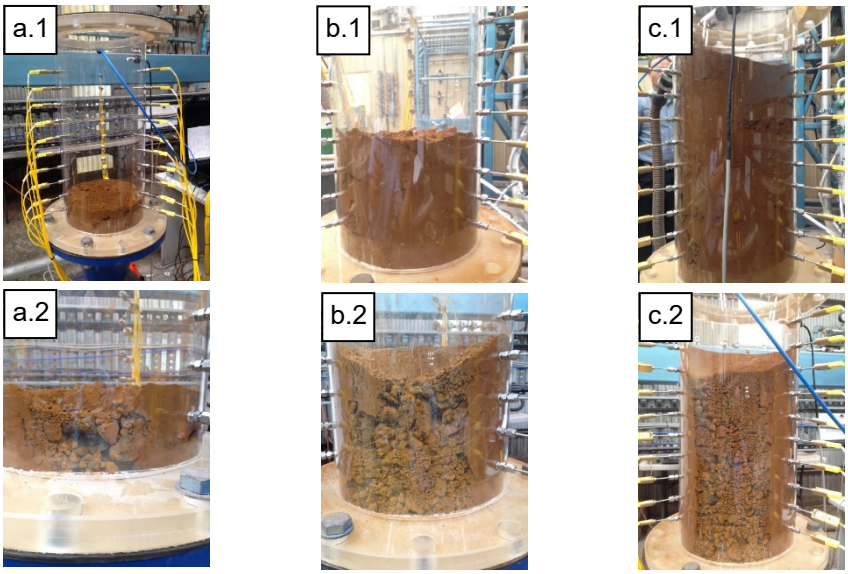

Figure 3 – a1, b1 and c1 are photos of the bed prior to air flow showing no channelling.

a2, b2 and c2 are photos of the bed after air has been induced showing the channelling effect.

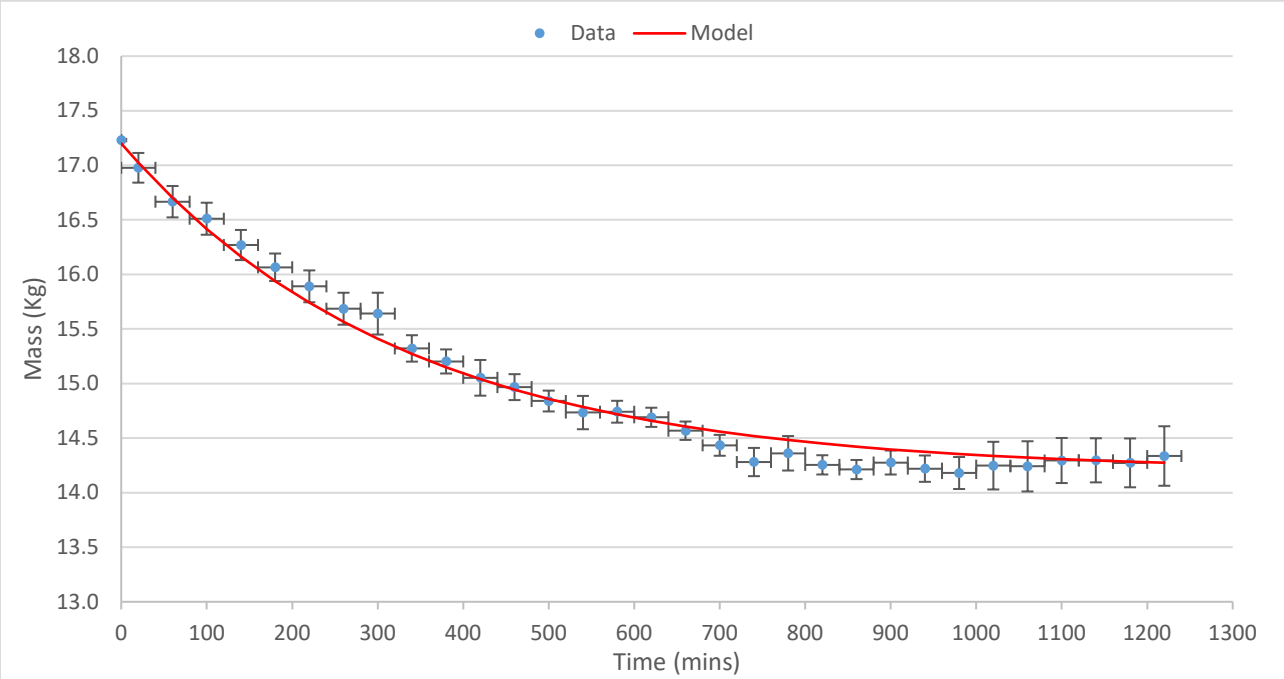

Figure 4a – Graph of the mass loss showing the models fit to the experimental data. Experimental conditions: air temp 23°C, air flow rate 0.2m^3/min, initial 17.3 kg (MC = 21.8%) and bed height 145mm. Model parameters: k_1=0.003.

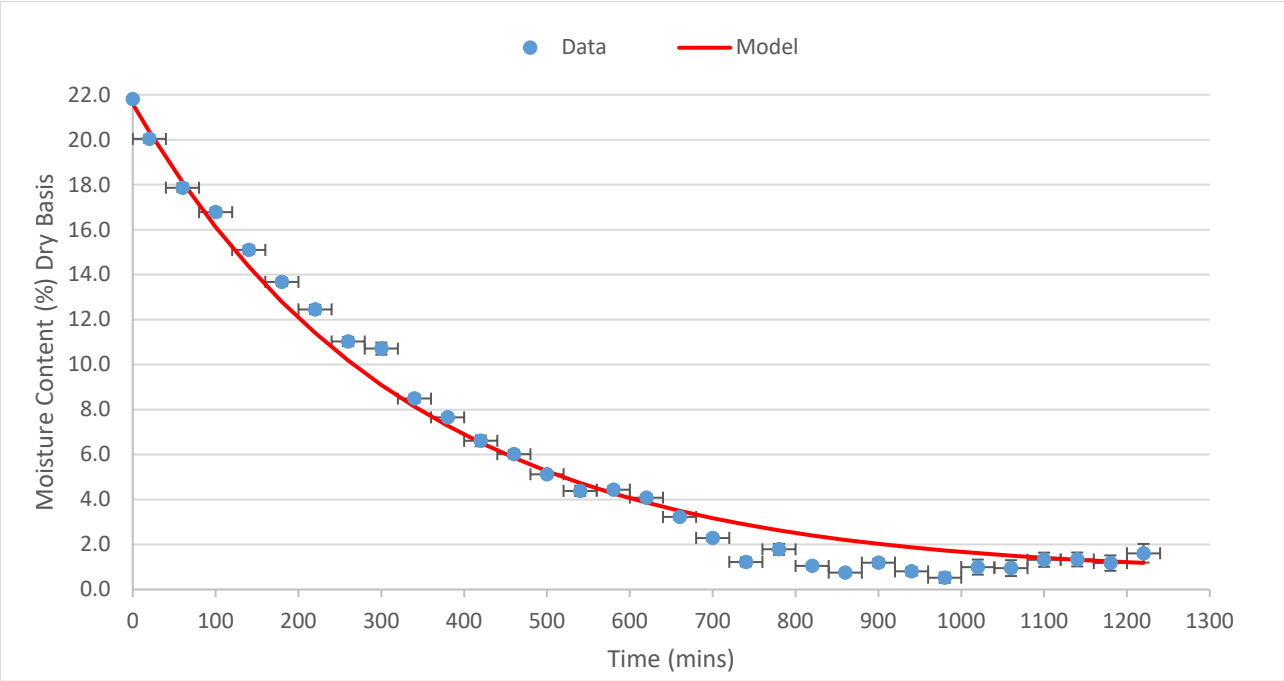

Figure 4b – Experimental moisture content change versus model prediction. Experimental conditions: air temp 23°C, air flow rate 0.2m³/min, initial MC 21.8% and bed height 145mm. Model parameters: k_1=0.003.