PROGRESS TOWARDS BETTER PRECISION AND IMPROVED SAFETY

Miles Grafton[1] and Ian Yule[2]

[1]*Ravensdown Fertiliser Co-operative Ltd. Christchurch, New Zealand,*
[2]*New Zealand Centre for Precision Agriculture, Institute of Natural Resources, Massey University, Palmerston North, New Zealand*

Abstract.
Safety and product placement precision is reviewed in this paper from the perspective of modifying materials applied by agricultural aircraft. It discusses methods and costs to overcome the problems outlined.

Improved safety of bulk solid fertilisers can be gained by ensuring the materials supplied for aerial application are free flowing. Mass flow rates of free flowing materials are predictable as they obey the “Beverloo equation”. Not all products delivered from aircraft are free flowing; the most problematic is agricultural limestone (lime).

Applying lime from fixed wing aircraft on hill country pasture in New Zealand has incurred a disproportionate number of accidents. Most lime is hammer milled to meet the Fertmark® standard, which requires that 95% by weight must pass through a 2mm (10 mesh) diameter screen and 50% by weight through a 0.5 mm (35 mesh) screen. The resulting product is cohesive, with varying bulk densities, both within and between quarries. Inconsistent flow properties have led to difficulties discharging lime from aircraft.

The problem is caused by a large range of particle sizes which are able to pack and form cohesive bridges preventing discharge. A free flowing non compactable product may be produced by having a narrow particle size range or by removing most of the particles below 0.5 mm.

There are two other products; di-calcic phosphate and reactive phosphate rock which are also commonly applied with a high proportion of fines. Because of their high drag coefficient particles below 0.5 mm in diameter can not be modelled predictably as to where they will deposit, which makes precision application impossible.

Keywords: Beverloo, Fertmark, lime, di-calcic phosphate, free flowing, cohesive, bulk solids

Introduction

Both safety and placement precision are compromised by the presence of fines, which for the purposes of this paper will be defined as particles less than 0.5mm in diameter. These particles generally have a drag coefficient that is too large for their deposition from an aircraft to be modelled by particle ballistics, Jones *et al*, (2008).

There are safety issues which result from the high percentage of fines in lime which is the most problematic of the bulk solids applied by aircraft, Grafton *et al*, (2009 a and b).

Although all twelve limes tested became free flowing once most of the fines below 0.5mm were removed, Grafton *et al*, (2010 and 2011a).

These findings have led to the Fertiliser Quality Council agreeing to a new Fertmark® aerial standard on 14 November 2011. This is a modification of the previous lime standard which requires that lime has an acid neutralising effect of 65% Calcium carbonate, and 95% of particles by weight must pass through a 2mm (10 mesh) diameter screen and 50% by weight through a 0.5 mm (35 mesh) screen, Fertiliser Quality Council (2004). The new aerial standard modifies the standard by requiring no more than 2.5% by weight should pass through a 0.5 mm screen.

In addition to lime di-calcic phosphate and reactive phosphate rock also have a large proportion of fines; however these pose less of a safety risk than lime to aviators. All three products are prone to chemical trespass as the fines frequently land off target, Yule *et al*, (2008). An agricultural pilot has recently been fined in the Waikato; for depositing lime in a lake as a result of off target drift.

These are significant changes for the industry and additional costs will have to be passed on to the farmer who has already demonstrated that their behaviour is sensitive to pricing as reflected in the elasticity of demand for these products. (Grafton et al 2011) Clearly there is a requirement to provide information and education on why these changes are necessary and the advantages that such a development will bring, not least providing a safer work environment for agricultural pilots. Although the fatality rate has been reduced in recent years, the overall accident rate has not. In the last three years the accident rate is still trending up according to the Aviation Industry Update June 2011, (Anon). Current accident costs are declining because recent accidents have been less serious, not because the overall rate is declining. Unfortunately it is only a matter of time before further pilots are killed.

It will also be difficult to demonstrate and prove a real financial benefit to farmers, as it is unlikely that any long term trials will ever take place due to cost, to establish the benefit of better placement of fertiliser and lime products in our hill country. In field CV has been calculated by Murray *et al*, (2007) at 78% and the modelled costs, in terms of fertiliser performance, are greater than the cost of application, Grafton *et al*, (2011b). The cost in terms of loss of fertiliser efficacy with increasing CV grows exponentially, Lawrence and Yule (2007) and Miller *et al*, (2009). Therefore, the cost of modifying materials to make them free flowing should both improve safety and allow improvement in delivery systems.

The costs of aircraft accidents has not been included in this analysis, it is not included in calculating the overall cost of operating a topdressing aircraft but it will be reflected in the insurance premium the operator is required to pay. The current estimated social cost of agricultural aviation accidents is just under $60 per operating hour. In the last ten years that has meant a total cost of $60M arising from agricultural aviation accidents. This does not include the loss of aircraft or the cost of aircraft repair, it is the social cost incurred through, healthcare, legal, property damage costs and estimates of lost output. While poor flow of material from the aircraft hopper is not a contributing factor to all agricultural aviation accidents it is a significant factor.

The problem the industry faces is finding means of removing most of the fines from these substances that:

- Is more cost effective than pelletizing or forming a prill
- Finds a commercial use for the fines removed

This paper examines the means of solving the problem of providing a particle size cut and outlines the costs involved.

Methods

Lime is available as a free flowing product prill but it is about NZ $100 per tonne more expensive than crushed agricultural lime that meets the Fertmark® standard. Lime is a low value farm input and NZ$100 is about four times the cost of a tonne of standard agricultural lime, which varies between $21 Webster's and $40 per tonne for Westport Lime (Ravensdown Price List 2, December 2011)..

Unassisted screening

Some quarries do screen lime, although the cut achieved from screening is at a particle size cut between 2 - 3 mm, (Pers. Comm. M. Rorisson, Managing Director of Rorisson Lime, 2009). The reason for screening lime is to improve the flow and is undertaken when the lime is dry; screening of lime that is not extremely dry is not possible as the screen blocks. Because of the cohesive properties of lime, screening below 2mm is not possible commercially as the screen needs to be continuously cleared.

Although screening to 2 – 3mm does produce a free flowing lime it considerably slows the acid neutralising effect in the short term as this is proportional to the particle surface area, Nye and Ameloko (1987). For situations where a liming effect is not required immediately, such as on farms which are regularly limed, rather than those where it is periodically applied then screening to this particle size cut appears to be a satisfactory solution.

Assisted screening

There are methods of assisting screening which involve moving the screen or the bed (dry jigging) which improve screening as they increase the probability of particles passing through the screen. Under reciprocating vibrating systems larger particles tend to move to the surface and smaller particles percolate to the bottom through the screen, Gotoh *et al*, (2006).

These methods are unlikely to be successful with lime as the cohesive properties are a result of particle packing, Grafton *et al*, (2009a, 2009b, 2010 and 2011a). Discussions with commercial suppliers of particle separation equipment support this hypothesis, (Pers. Comm. Mr. Chris Martin, President RSG Inc. Dec. 2011, Mr. Darrell Malczewski, Regional Sales Manager Prater-Sterling, Dec. 2011 and Mr. Clarence Kreiser, Global Production Manager, Metso Mining and Construction Ltd., Dec. 2011). All considered that the high proportion of material, (around 50% by weight), that is required to be removed would make screening difficult with non cohesive materials and impossible with cohesive materials.

Air Classifiers

One of the problems any separation at a particle size cut is the moisture content of the material being separated. The moisture content of New Zealand lime deposits when hammer milled varies between 0 – 13%. Although, there are significant periods when quarries are able to supply material with moisture content less than 2% by weight, (Pers Comm., Quality

Assurance Data Base supplied by: Mr. R. Kinney, Lime Works Manager, Ravensdown Fertiliser Co-op Ltd., 2008). This is significant as even pressurised classification systems require moisture content less than 2 - 2.5% by weight. This means that installing in-line drying facilities is probably required in most quarries; otherwise for long periods the material milled will be unsuitable for classifying.

There are two main types of air classifier; static or gravitational assisted and dynamic centrifugal separators; see Figures 1a and b (Source, Buell classifiers by Fisher Kleistermann, PA,l USA).

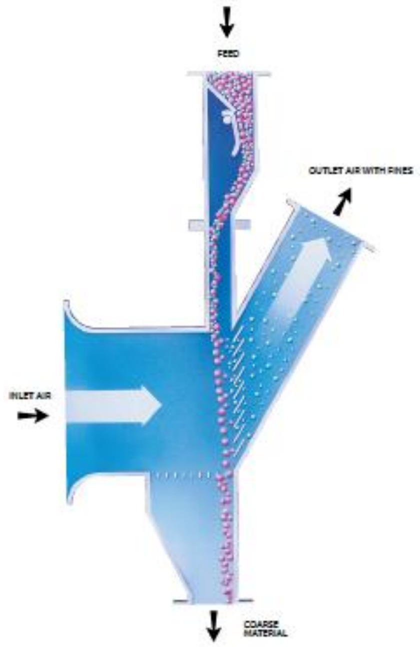

Figure 1a: static air classifier

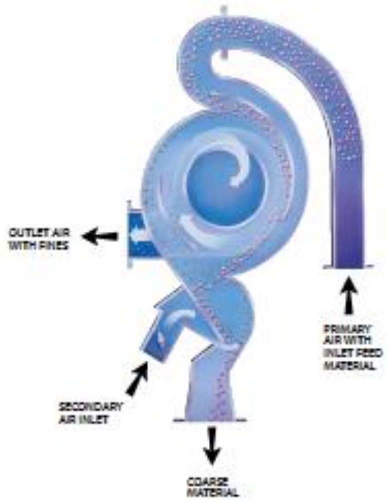

Figure 1b: dynamic air classifier

The static classifiers effectiveness increases with the length of the drop of the feed material. It is for this reason that they are usually tall structures when handling large inputs, say 40 tonnes per hour, see Figure 2.

They work by feeding the mixture through the top and using pressurised air input to remove the lighter particles through a screen mesh, set to the specific cut, which for aerial lime would be 0.5mm, Gotoh *et al*, (2006).

Dynamic air classifiers operate by separating the heavier particles using centrifugal force which exit from the outside of the centrifuge, smaller particles are removed through a screen set at the specified cut, Gotoh *et al*, (2006). Dynamic separators occupy less space and are more efficient, for example large dynamic separators can process up to 100 tonnes of material in an hour, see Figure 3.

Drying

A schematic of a spin flash dryer, continuous process system in line drying is shown in Figure 4. Heat is produced by gas or oil burning which heats the air intake at the "blue arrow". The moisture laden powder is introduced at the "green arrow", the material spun in the drying chamber, the mixture is then dried and spun out through the yellow outlet pipe and the dry product "green and yellow arrow" product leaves the hopper and the moisture laden air via the "yellow arrow". Spin flash dryers come in many sizes and can remove up to 8 tonnes of moisture per hour from powder.

Figure 2: Shows a Metso static classifier (Source: Metso mining and Construction ltd.)

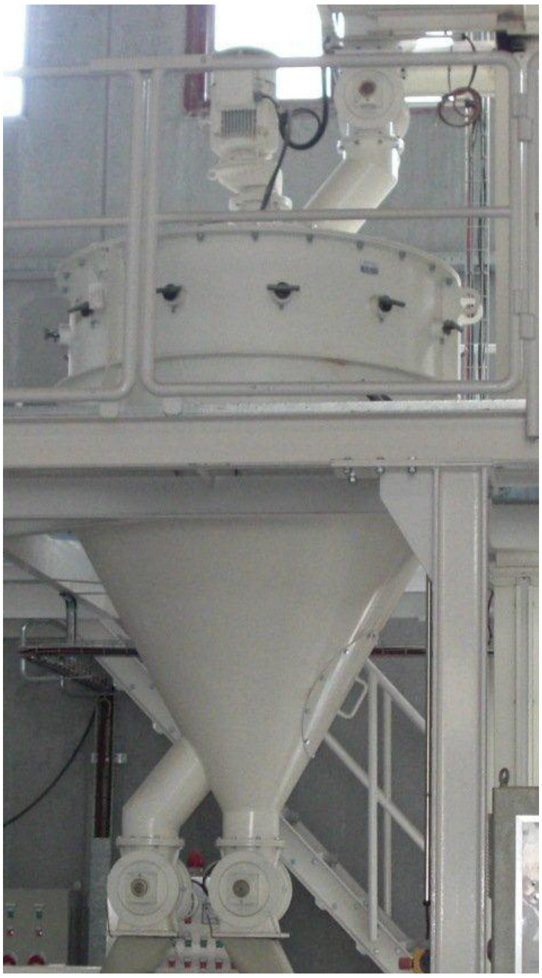

Figure 3: Shows ULS Dynamic Classifier (Source: Ecutec SL, Catalane , Spain)_

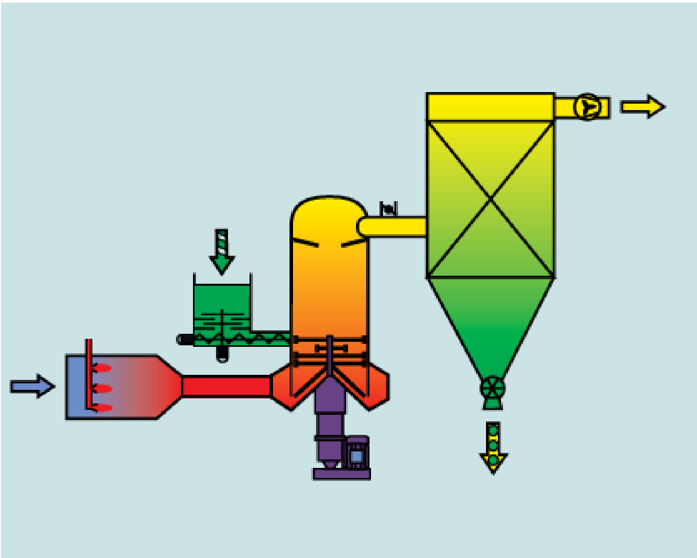

Figure 4: Shows in line drying by spin flash dryer (Source: Anhydro spin flash dryer www.spxf.com)

Results

Indicative Process Cost

Indicative costs to drying and separating lime to reach the new aerial Fertmark® standard were calculated from a desktop study based on the following assumptions:

- Processing 50 tonnes of crushed limestone per hour
- Reducing the moisture content from 13% - 2% in a spin flash dryer
- Using a dynamic classifier to remove 97.5% of particles less than 0.5mm
- Assuming limestone entering spin flash dryer is at 10°C
- Latent heat of water 4,187 KJ/Kg and of evaporation and of evaporation 2,270 KJ/Kg
- Diesel releases 39.6 MJ/litre at $1.50 /litre
- Spin flash dryer is 50% efficient
- The spin flash dryer operates at 400 KW to drive spinner at $0.20/ KWhr
- The dynamic classifier operates at 380 KW at $0.20/KWhr
- Depreciation is 16% (Inland Revenue IR 265)
- Maintenance is 5% of capital value
- A spin flash dryer costs $150,000
- A dynamic classifier costs $450,000
- Fitting costs $50,000
- Production 37,500 tonnes aerial lime from 1,650 hours operation

For indicative costs for processing lime into aerial lime, see Table 1.

Table 1: Costs of processing lime to manufacture aerial lime in commercial quantities

Spin Flash Dryer	*Cost per hour ($)*	*Cost per annum ($)*	*Cost per tonne aerial ($)*
Diesel	**186**	**306,900**	**8.16**
Electricity	**80**	**132,000**	**3.52**
Depreciation	**17**	**28,000**	**0.75**
Maintenance	**5**	**8,750**	**0.23**
SubTotal	**288**	**475,650**	**12.68**
Dynamic Separator			
Electricity	**76**	**125,400**	**3.34**
Depreciation	**46**	**76,000**	**2.03**
Maintenance	**14**	**23,750**	**0.63**
Sub Total	**136**	**225,150**	**6.00**
Total	**424**	**700,800**	**18.68**

The indicative cost of producing 37,500 tonnes of aerial lime if all of it needs to be dried before processing is $18.68 per tonne. However, there is still another 37,500 tonnes of material which is still available for use in non aerial application which reduces the cost per tonne processed to $9.34 per tonne.

Discussion

Improved precision

It is only when all products being used are free flowing that aircraft precision can be improved both in terms of drift, by removing fines and with improved safety in terms of predictable free flowing substances.

There are commercial differential Global Positioning Systems (DGPS) available which can control a hopper door based on calibrated flow parameters. Such systems can only be employed on an aircraft if the products applied have known flow properties; therefore they need to be free flowing.

A further advantage of these products flow predictability is that they can be more easily tested, the authors are investigating tests methods that could be adopted both at dispatch and when the material is being applied which would give an indication of potential problems. Because the present products are not free flowing their behaviour is not predictable enough to reliably test.

The basis of the test would be that free flowing bulk solids obey the "Beverloo Equation", Beverloo *et al*, (1961):

$$M = K\rho g^{\frac{1}{2}} L(B - k\bar{d})^{\frac{3}{2}}$$

M	is mass flow rate
K	a constant for superphosphate ≈ 0.58
ρ	Is the bulk density ≈ 1,160 kgm-3
g	Is acceleration due to gravity 9.83ms-2
k	a constant for superphosphate ≈ 1.7
d	Is the mean diameter of the particles ≈0.0033m
L	Is the length of the hopper door opening for a Cresco = 1.048m
B	is the breadth of the varying opening - the maximum dump opening is 0.34m

Equation (1) depicts the parameters for adjusting the opening if using superphosphate from a Cresco agricultural aircraft.

Conclusion

It is apparent that it will be more economic to achieve a particle size cut than to purchase pelletized lime and di-calcic phosphate. The improvements in safety alone should make the increased cost of using the aerial standard lime viable. However, the potential benefits in terms of allowing development of permanent solid flow control mechanisms in aircraft should improve the precision of fertiliser placement and these benefits are likely to outweigh the extra application costs.

References:

Anon. (2011) Aviation Industry Safety Update, 1 January to 30 June 2011. http://www.caa.govt.nz/Safety_Reports/2011-1_Safety_Update.pdf Accessed 12th January 2012.

Beverloo W, Leniger H., van de Velde J, 1961, The flow of granular solids through orifices, Chemical Engineering Science, Vol 13, pp 260 – 269.

Gotoh, K., Masuda, H., Yoshida, H., Hidaka, J., Classification, In: Powder Technology Handbook Third Edition, 2006 Chapter 5.2, (Eds H. Masuda, K. Higashitani, H. Yoshida), Taylor and Francis Group, New York, Pp 527 – 550.

Grafton, M. C. E., Yule I. J., Davies, C. E. and Jones, J. R. 2009a, Incidents and accidents in aerial topdressing in New Zealand: Causes and approaches to mitigation, Proc. The 6th International Conference for Conveying and Handling of particulate Solids, Brisbane, Australia, 3-7 August.

Grafton, M. C. E., Davies, C. E., Jones, J. R., Yule, I. J. 2009b, Comparative Study of the Cohesive Properties of Commercial Agricultural Crushed Limestone of New Zealand, Proc. The 6th International Conference for Conveying and Handling of particulate Solids, Brisbane, Australia, 3-7 August.

Grafton, MCE, Yule, IJ, Davies, CE, Jones, JR, 2010, Analysis of Material Flow from Topdressing Aircraft, In: Farming's future: minimizing footprints and maximizing margins. (Eds L.D. Currie and C.L. Christensen). Occasional Report No. 23. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp 421 – 428.

Grafton M.C.E.., Yule I.J., Stewart R.B.., Davies C.E., Jones J.R., 2011a. Resolving the Agricultural Crushed Limestone Flow Problem from Fixed Wing Aircraft, *Trans. ASABE* Vol 54(3):769 - 775.

Grafton, M.C.E., Yule, I..J.., Manning, M.J.., 2011b, Analysis of Material Flow from Topdressing Aircraft, In: Farming's future: minimizing footprints and maximizing margins. (Eds L.D. Currie and C.L. Christensen). Occasional Report No. 24. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 14 Pages.

Inland Revenue, 2007, IR 265 Depreciation rates

Jones JR, Murray RI, Yule IJ, May – June 2008. Modeling the Coarse fraction of solid Fertilizer deposition from a Fixed-Wing Aircraft: A ballistics model: Transactions of the ASABE, Vol: 51, Issue 3. pp 857-877

Lawrence, H.G., Yule, I.J., 2007, Estimation of the In-field variation in Fertiliser Application, N.Z. Journal of Agriculture Research, Vol. 50: Pp 25-32

Miller P.C.H., Audsley, E., Richards, I.R., 2009, Costs and Effects of Uneven Spreading of Nitrogen Fertilisers, In: Proc. Of the international Fertiliser Society, No. 659: 14 pages

Murray, RI, Yule IJ, Gillingham AG, 2007, Developing variable rate application technology: modelling annual pasture production on hill country, New Zealand Journal of Agricultural Research Vol: 50 pp 41-52.

New Zealand Fertiliser Quality Council, Fertmark codes of practice. Retrieved 23 February 2009, from http://www.fertqual.co.nz , page 36

Nye, PH, Ameloko, AY, 1987, Predicting the rate of dissolution of lime in soil, Journ. of Soil Science, vol 38, pp 641-649.

Yule I.J., Grafton M.C.E., Murray R.I, 2008, Factors affecting the performance of variable rate application technology (VRAT) for aerial topdressing. Proceedings ASABE, Providence Rhode Island, June 29 – July 2, Paper 084025.