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Significance of Powder Breakdown during In-Plant Transport at Industrial Milk Powder Plants

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Abstract: Instant whole milk powder (IWMP) is designed to rapidly dissolve in water, which depends on the particle size distribution (PSD) and agglomeration. The warm and delicate milk powder exiting the dryer is transported via either pneumatic conveying or bucket elevators to packing. The gentleness of this powder transport process is important for IWMP, as it can break down the agglomerates, generating excess fines, which leads to poor dissolution properties. This work looked at the breakdown of milk powder at two different, geographically separate, industrial IWMP plants, using the Malvern Mastersizer, a laboratory laser diffraction instrument, and sieving, to evaluate the importance of breakdown on the final product properties given different conveying methods. It was found that the method of measurement affected the results, with sieves showing a larger powder size reduction during transport as compared with the Mastersizer. PSDs with a larger average size at the start of powder transport showed more breakdown, with a greater decrease in the average particle size. However, the larger decrease was not enough to compensate for the initially larger average particle size, and powder that started out with larger agglomerates at the fluidised beds still had a larger average particle size at packing. The Mastersizer appeared to break the large agglomerates during measurement, especially with powder that had not been through the entire transport line, thus masking the extent of the size reduction, however this could only occur to weaker agglomerates. Thus in order to produce IWMP with the desired functionalities, the focus should be on improving agglomeration as oppose to reducing transport breakdown to achieve the desired particle size distribution.

Keywords: milk powder, particle size, powder breakdown.

1 Introduction

Recently there has been a shift towards the implementation of process analytical technology (PAT) into the food industry. Although PAT has come to have different meanings in different industries, Fonterra has been looking to implement PAT in combination with advanced process control (APC) in order to develop 'real time quality' (RTQ) tools, specifically focusing on quality. Instant whole milk powder (IWMP) is industrially produced in large quantities, with infrequent quality testing that occurs with significant post production lag. This means that quality issues cannot be picked up until post production, when it is too late to rectify the problem. RTQ aims to predict the quality of the product in real time, in order to be able to prevent quality failure [1,2]. However, before this can be done, the cause of quality failure needs to be understood, so that the proper plant adjustments can be made.

IWMP is designed to rapidly reconstitute in water, and to achieve this two additional processing steps are carried out during production, over regular whole milk and skim milk powder production: agglomeration and lecithination. Whole milk powder contains a considerable fat fraction (~26%), which is hydrophobic and thus resists dispersion in water. Therefore, small quantities of an emulsifier, lecithin, are added to improve the wettability of the powder. Agglomeration involves the combination of multiple milk powder particles into clusters, in order to make the powder easily penetrable by water, and thus impart 'instant' dissolution properties [3,4].

Good powder instant properties favour the following agglomerate size distribution criteria [3]:

1) Low fines content – less than 20 % of particles smaller than 125 µm in size.

2) Low coarse particle fraction – less than 10 % of particles larger than 500 µm in size, depending on the agglomerate structure, as these can be slow to dissolve.

However, the agglomerates vary in strength, and can be easily broken during transportation, resulting in worsening of the desired instant dissolution properties, through the generation of excess fines. This is affected by the powder conveying method, with any pneumatic transport system causing some breakdown in the final powder [3]. Although dense phase pneumatic transport, with low velocities and air-to-powder ratios, reduces the agglomerate breakdown compared with lean phase transport, using bucket elevators is gentler still.

This work looked at the breakdown of milk powder at two different, geographically separate, industrial IWMP plants. The two plants had different transport systems, with Plant A having a bucket elevator and Plant B having a pneumatic conveying system. Plant A has historically consistently produced powder with superior instant functional properties and bulk density, compared with Plant B. It was suspected that this might be at least partially caused by reduced agglomerate breakdown due to the gentler bucket elevator transport system.

This hypothesis was investigated using the Malvern Mastersizer 2000, a laboratory laser diffraction instrument, and sieving, to evaluate the importance of breakdown to the final product properties observed at the plants.

2 Method and Materials

Samples were taken at two industrial IWMP plants, with the locations being discussed in Section 2.1. Two different methods were used to measure the particle sizes of the powders, the Mastersizer 2000 and sieving, with methodological details given in Sections 2.2 and 2.3 respectively.

2.1 Sampling Locations

A generic schematic of a dryer with the post drying transport chain is shown in Figure 1. The powder is dried in two stages, with the majority of the water being extracted in the spray dryer, and the final moisture removal occurring in the vibrating fluidised beds.

Samples were taken at four different locations in the two different plants, as shown in Figure 1; however it was not always possible to take them from corresponding locations. Only two sets of powder transport samples were taken at Plant A, meanwhile Plant B had nine.

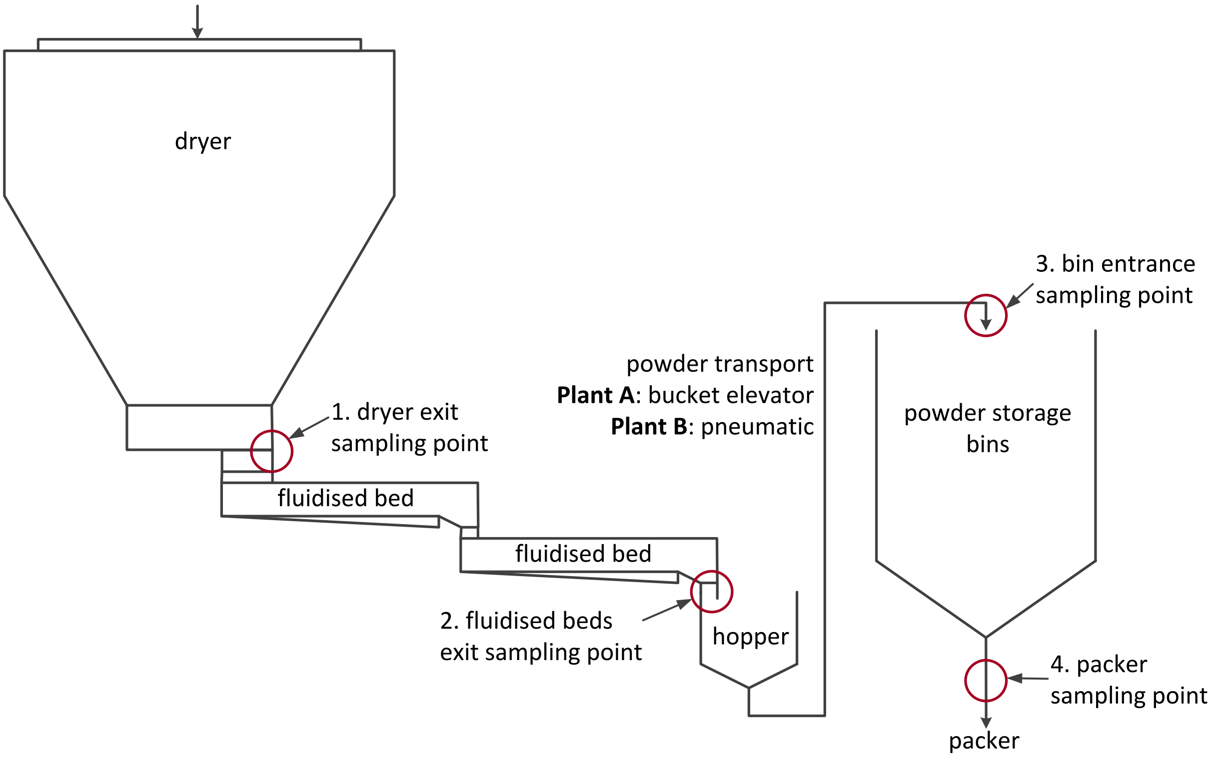


Figure 1: Generic drying plant schematic showing sampling locations.

2.2 Malvern Mastersizer 2000

The Malvern Mastersizer 2000, a laser diffraction instrument, was used to measure the dry particle size distribution of IWMP. Approximately 30 g of milk powder was put into the feed hopper. The metal ball bearings in the inlet sump were removed, as they caused attrition of the sample. The sample was initially mixed with a spatula and the feed pressure adjusted to 0.1 bar. A background reading was taken for 10 s before the powder feed flow rate was adjusted to reach the required laser obscuration of 1–5 %, which could be anywhere between 20–100 % of the maximum powder flow rate depending on the powder flowability. The sample measurement time was set to 20 s, with a refractive index of 1.46, and no absorption.

2.3 Sieving

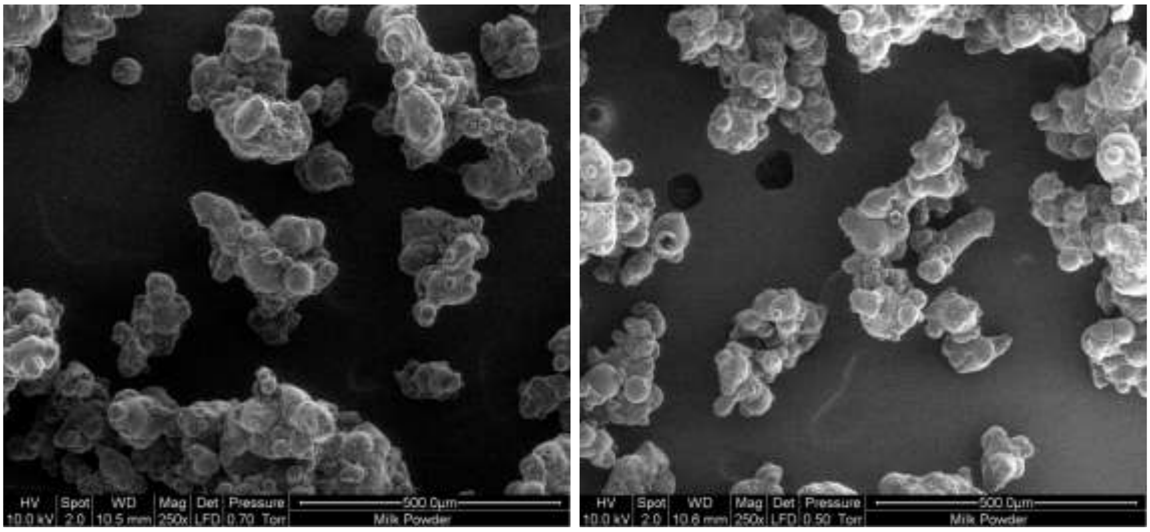
Sieving was also used to measure the particle size of the powder, however with a much lower particle size bin resolution. This was done as the particle size measurement is affected by the technique used [5]. Only two sieves were used, giving three size fractions, in order to minimise potential powder breakdown during measurement. 30 g of powder was weighed out and mixed with 1 % (wt/wt) Syloid 244 FP flow agent from Grace Davison, as IWMP has poor flowability characteristics. The powder was then fractionated using 125 and 355 µm aperture sieves, 200 mm in diameter, with a vibratory Retsch AS200 sieve shaker for 30 minutes. A brush was used to brush any powder stuck to the underside of the sieve into the one below it, and the powder remaining in each sieve weighed. The sieves were then cleaned with isopropanol before the next analysis.

3 Results and Discussion

The powders produced at the packer of each plant were initially characterised in Section 3.1, in order to understand the differences between the powders produced at the different plants. The agglomerate breakdown at each plant was then evaluated and compared using the Mastersizer in Section 3.2. The final section looks at how the measurement technique could have affected the results, and thus the conclusions drawn from the analysis.

3.1 Characterisation of Milk Powder Produced at the Different Plants

Scanning electron micrographs (SEMs) of the powders produced at Plant A and Plant B are shown in Figure 2. Agglomeration is evident in the photos with large lumps composed of small spheres. The powders produced look very similar in nature, although the exhibit different functional properties, with Plant A having the superior instant dissolution behaviour. The differences between the powders are not obvious, however SEMs do not necessarily show the bulk properties of the powders.



(a) (b)

Figure 2: SEM images of powder from a) Plant A and b) Plant B

The particle size distribution of the powder measured at the packer was found to be significantly different between the two plants. A comparison of the distributions is shown in Figure 3. It is clear that the powder produced at Plant A has a significantly larger average particle size; with a median diameter, *d(0.5)*, that was on average 83 µm larger than the powder produced at Plant B. Average *d(0.5)* values of the powder produced at the two plants are shown in Table 1. Figure 3 also shows that Plant A also has a much larger variation in the particle size distribution between different samples, whilst Plant B produced powder that was more consistent in size.

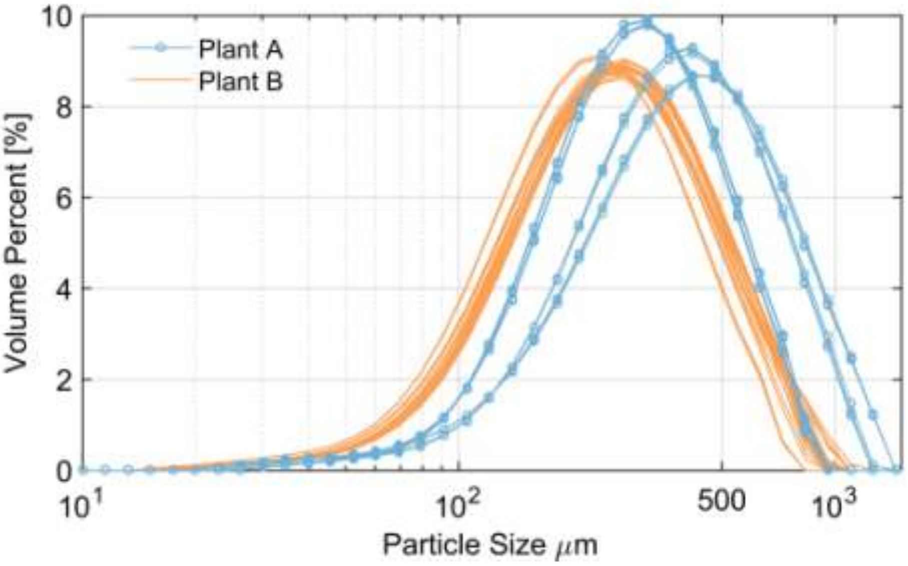


Figure 3: Comparison of particle size distributions measured at the packer (position 1) at the two plants.

Table 1: Average *d(0.5)* of different packer samples from Plant A and Plant B

	Plant A	**Plant B**
Number of samples	4	11
Average *d(0.5)* ±*s* (µm)	316 ±52	233 ±15

The particle size distribution was measured using the Mastersizer, and prior research carried out by Chen and Lloyd [6] using an older model of the instrument found that the air dispersion of the particles resulted in unpredictable agglomerate breakdown of some of the agglomerated powders. Therefore, some of the samples were also tested using sieves, to evaluate that the large difference in the particle size between the two plants was not due to agglomerate breakdown in the instrument. The sieved fines fraction (<125 µm) was indeed significantly smaller for Plant A, at 7-10%, than Plant B, at 14-19%, and similarly Plant A had a larger coarse fraction. Therefore the sieving results for the packer samples were consistent with the Mastersizer results.

It was hypothesised that the larger average particle size at the packer was at least partially due to the gentler bucket elevator transport system, resulting in less powder breakdown during transport. It was also hypothesised that this was the reason that powder from Plant A consistently showed superior dispersing properties. Thus, samples were measured at different points in the transport chain.

3.2 Milk Powder Breakdown during Conveying

Example cumulative distribution functions measured with the Mastersizer are shown in Figures 4 and 5 for Plants A and B respectively. The *d(0.5)* is shown on the x-axis to clearly show the decrease in the particle size across the conveying system. The decrease from the fluidised beds to the packer varied between 20-43 µm for Plant A and between 0.3-24 µm for Plant B, signifying that Plant A showed a larger change in the particle size due to transport than Plant B. This was contrary to the hypothesis, that Plant A with the bucket elevator transport was expected to show a smaller breakdown.

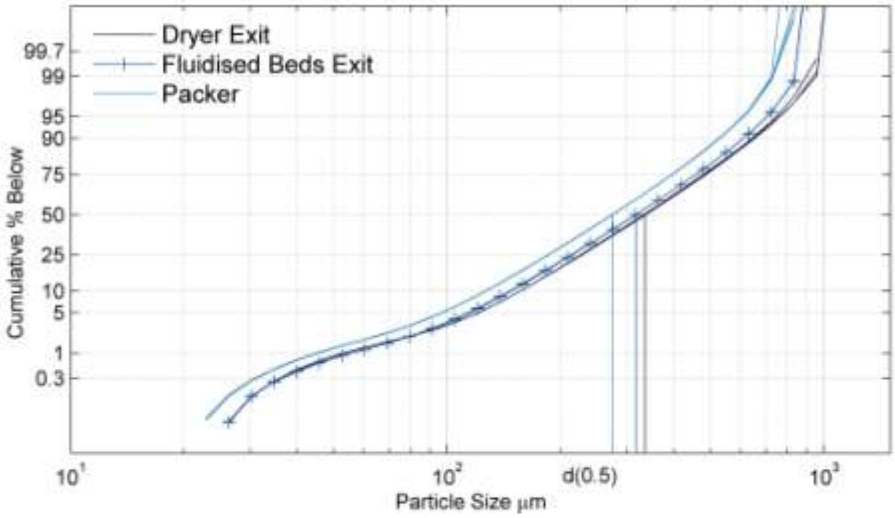


Figure 4 Example of the change in the cumulative particle size distribution of IWMP produced at Plant A.

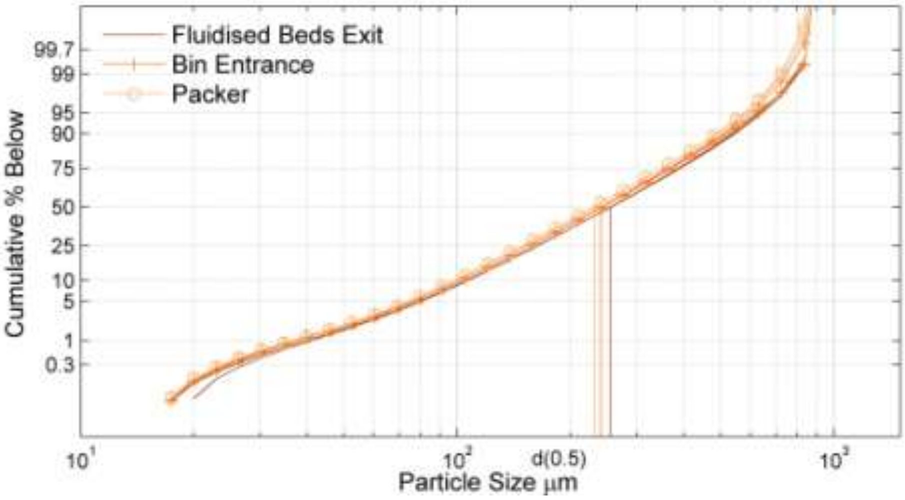
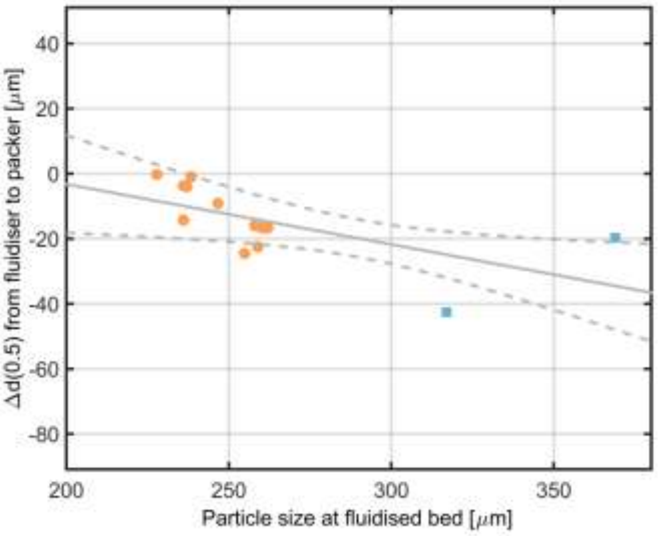
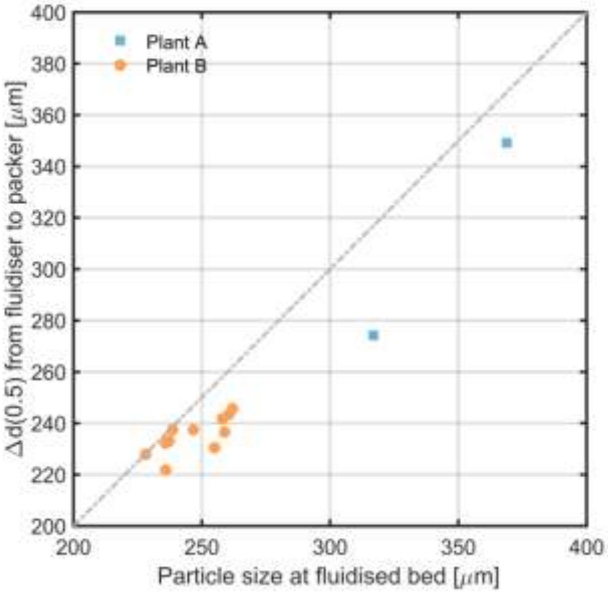


Figure 5: Example of the change in the cumulative particle size distribution of IWMP produced at Plant B

The only corresponding samples that could be compared directly between the two plants for changes were the samples taken at the end of the fluidised bed and at the packer. Figure 6a shows a graph of the decrease in the median particle size across the transport chain plotted against the particle size at the end of the fluidised beds for both plants. A fitted curve with 95 % confidence intervals is overlaid. Particles with an initially larger size at the fluidised beds show a larger decrease in the particle size. This indicates that the larger the agglomerates, the more likely they are to breakdown, irrespective of the plant conveying system. This implies that the larger average particle size distribution at Plant A is not due to the bucket elevator, as it experiences more powder breakdown than the powder at Plant B.



(a)



(b)

Figure 6: Effect of the initial particle size at the exit of the fluidised beds on a) the particle size breakdown through transport and b) the particle size at the packer.

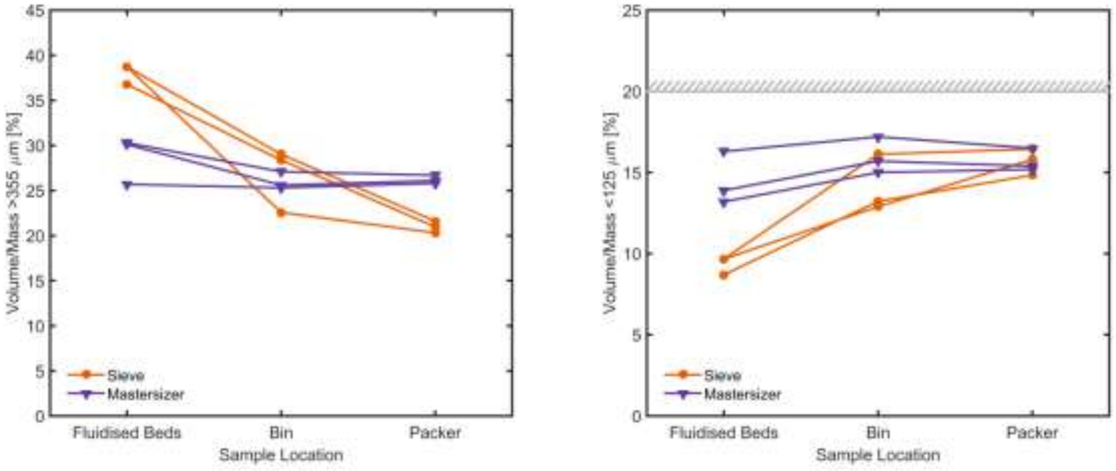
Figure 6b shows the median diameter at the packer plotted against the initial median diameter at the fluidised beds for both plants. It can be see that even though the larger particles may experience more breakdown, the net effect is that the median particle size at the packer is still larger. Plant A always has a significantly lower fraction of fines, in spite of the higher breakdown during transport, which means that the transport chain favours an initially larger particle size distribution prior, in order to have a buffer for agglomerate breakdown to occur.

This data suggests that if the buffer is sufficiently large, then particle breakdown is less relevant to the final dissolution properties of the powder, as Plant A exhibits superior instant properties to Plant B. However, if the initial particle size is on the lower end, and sufficient breakdown occurs, then the powder has a large fines content at the outset, which would be expected to increase towards the end of the transport chain, increasing the fines further and worsening the instant powder dissolution properties. Thus, the focus for achieving the right particle size at the packer should be on achieving the right particle size at the dryer at the outset, such that it can compensate for transport through the system, which cannot be avoided, nor changed significantly once installed.

3.3 Comparison of Breakdown Measured Using Mastersizer with Sieving

The breakdown in the transport chain was also measured using sieves. Even though the packer samples between the two plants showed consistent results when measured with the Mastersizer and sieves, powder that has not been subjected to the transport chain was still likely to contain the weaker agglomerates. These weaker agglomerates would have been more prone to breakdown, and thus sieving was used to investigate if the measurement technique affected the powder transport results.

Figure 7 shows a comparison of the coarse and fine fractions in the IWMP during transport, as measured by the Mastersizer and using two sieves. It can be seen that fraction of coarse material measured by the Mastersizer, does not change significantly from the fluidised beds, to the bin and the packer, with a measured decrease of less than 5 %. Whilst when the change in coarse material is measured using sieves, the coarse fraction decreases by around 20 %, indicating a larger breakdown. Similarly, the volume of fines measured by the Mastersizer only increases marginally, whilst sieving shows a clear upward trend. Therefore, the breakdown occurring during transport is probably larger than that measured by the Mastersizer, most likely because the Mastersizer is breaking up the more fragile agglomerates that have not been broken down by the powder transport prior to measurement.



(a) (b)

Figure 7: Comparison of breakdown during powder transport when measured by the Mastersizer with sieving a) coarse particle size fraction b) fine particle size fraction with a hatched line for the upper recommended limit of fines based on Pisecky [3] discussed in Section 1.0.

This indicates that the powder breakdown is strongly affected by the agglomerate strength, with stronger agglomerates being able to be measured more accurately by the Mastersizer, without breakdown. A comparison of what the expected sieving and Mastersizer results would be for weak and strong agglomerates is shown in Figure 8. If the agglomerates are strong, then it is expected that the fine and coarse fractions would be consistent when analysed using either the Mastersizer or sieving, irrespective of the sampling location (position in the transport chain). However, if the agglomerates are weak, then they would be expected to be broken down in the Mastersizer, and thus the results with sieving should diverge based on the sampling position. When the powder reaches the packer, most weak agglomerates may be expected to be already broken, unlike at the start of transport, thus leaving fewer weak agglomerates to be broken in the Mastersizer during analysis. More data is being gathered to support this hypothesis. Irregardless, this still suggests that the agglomerate structure prior to transport within the plant is more important than optimisation of the transport within the plant.

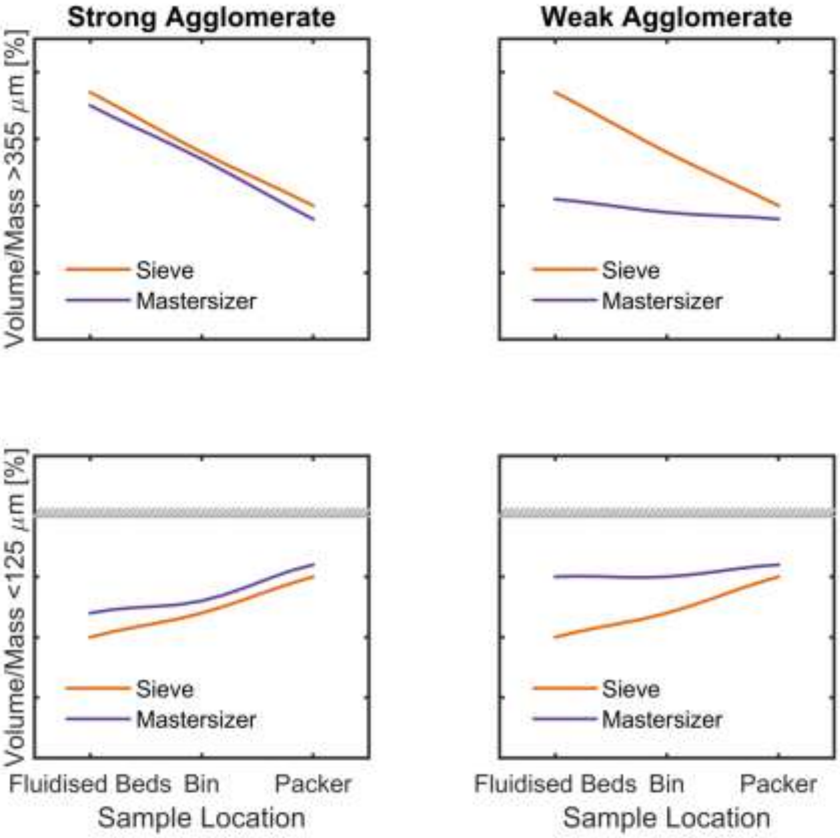


Figure 8: Hypothesised profiles of the particle size distributions measured by sieving and the Mastersizer through the transport chain depending on agglomerate strength with a hatched line for the upper recommended limit of fines based on Pisecky [3] discussed in Section 1.0.

4 Conclusions

The breakdown of IWMP during processing was studied at two different industrial plants. The particle size distribution affects the instant dissolution properties of the powder, with excess fine particles being detrimental to the powder functionality. It was expected prior to this study that the plant with the more gentle powder transport system, Plant A, ended up with a larger final particle size, compared with Plant B, due to less powder breakdown. As measured by the Mastersizer, it appears that the powder from Plant A had significantly larger particles prior to transport, which provided a larger buffer for breakdown. This would indicate that to achieve the ideal IWMP particle size, the focus should be on achieving a larger particle size initially. However, this data depended on the measurement technique, and sieving indicates a larger degree of breakdown during measurement for Plant B, indicating that the agglomerates may be weaker. This refocuses the strategy for achieving the desired particle size distribution post transport on the agglomerate strength. Overall the results indicate that the focus should be on the agglomerate size and structure prior to transport, as opposed to optimising (or even being concerned with) the powder transport line.

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Presenting author biography

Irina completed her PhD in Chemical Engineering at the University of Auckland. She has experience working as a process engineer at Harrison Grierson Consultants in water treatment plant design and is currently employed as a postdoctoral fellow at the University of Auckland, lecturing, carrying out research, and assisting in student supervision. Her primary focus is predicting the quality of milk powder in real time using modelling, laboratory experimentation and plant scale data analysis for Fonterra.

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