ADVANCES IN NUTRITIONAL DAIRY PRODUCTS AND INGREDIENTS: Opportunities & Challenges

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How Composition Affects Processing

Overview

This presentation examines the interactions between product formulation and processing for nutritional and other specialty powders.

My main focus is on the spray drying of these powders.

I’m adopting an engineer’s approach, applying scientific research in practical applications.

How Composition Affects Processing

Overview

The criteria for formulating these powders are, in order of importance:

- Nutritional requirements (gross composition, minor ingredients and micronutrients)
- Functional properties (varying with the application)
- Ingredient cost
- Ease of manufacture

How Composition Affects Processing

Overview

Ease of manufacture usually comes in last and is often seen as a problem for the plant staff to sort out once the formulation is fixed.

Commonly, once a recipe has been developed and production begun, fine tuning of the processing variables can increase the production rate and reduce energy, cleaning chemical and labour inputs.

How Composition Affects Processing

Overview

Just when all is finally going well, an opportunity comes along to reduce ingredient costs or eliminate a particular ingredient for marketing reasons by changing ingredients or ingredient suppliers while keeping the product gross composition "the same".

Often this affects the way the product handles in the wet processing, spray drying and powder transport and packaging systems.

In this presentation I focus on the impact of ingredient changes on the spray dryer.

How Composition Affects Processing

Composition

Compositional changes affect many aspects of the processing of spray dried dairy products:

- Recombining, air incorporation, hydration, dissolving
- Fouling of heat transfer surfaces
- Concentrate viscosity and its effects on atomization and droplet drying
- Powder stickiness

How Composition Affects Processing

Composition

The predominant mechanism by which composition changes affect processing is through viscosity:

- Viscosity of the ingredients as they are mixed
- Viscosity of the mix as it is membrane concentrated or evaporated
- Viscosity of the concentrate as it is heated, atomized and spray dried
- Viscosity of the surface of the powder particles as they dry and are transported and packed - stickiness

How Composition Affects Processing

Powder Stickiness

Three key insights:

1. It is the OUTSIDE SURFACE of a particle which sticks.
2. It is the VISCOSITY of the particle SURFACE which determines its stickiness.
3. The surface viscosity of a particle is determined by its COMPOSITION and the TEMPERATURE and RELATIVE HUMIDITY of the air surrounding it.

How Composition Affects Processing

Powder Stickiness

Only the OUTSIDE SURFACE of a particle can stick to anything

Moisture and stickiness are NOT related

Powder particles dry from the outside in, so the surface can be dry and non-sticky while the average moisture content can be quite high

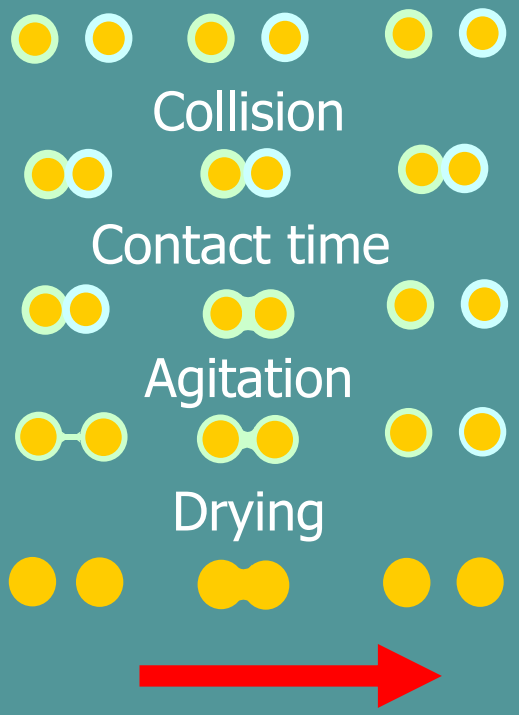
How Composition Affects Processing

The Stickiness Mechanism

For many food and other powders, stickiness occurs when the viscosity of the amorphous surface of the particles lies in the range:

0.3×10^{10} - 4.0×10^{10} centipoise

(i.e. 3 to 40 billion centipoise)



Downton, G E, J L Flores-Luna and C J King "Mechanism of Stickiness in Hygroscopic, Amorphous Powders" Industrial Engineering Chemistry Fundamentals, Vol. 21, 447-451 (1982)

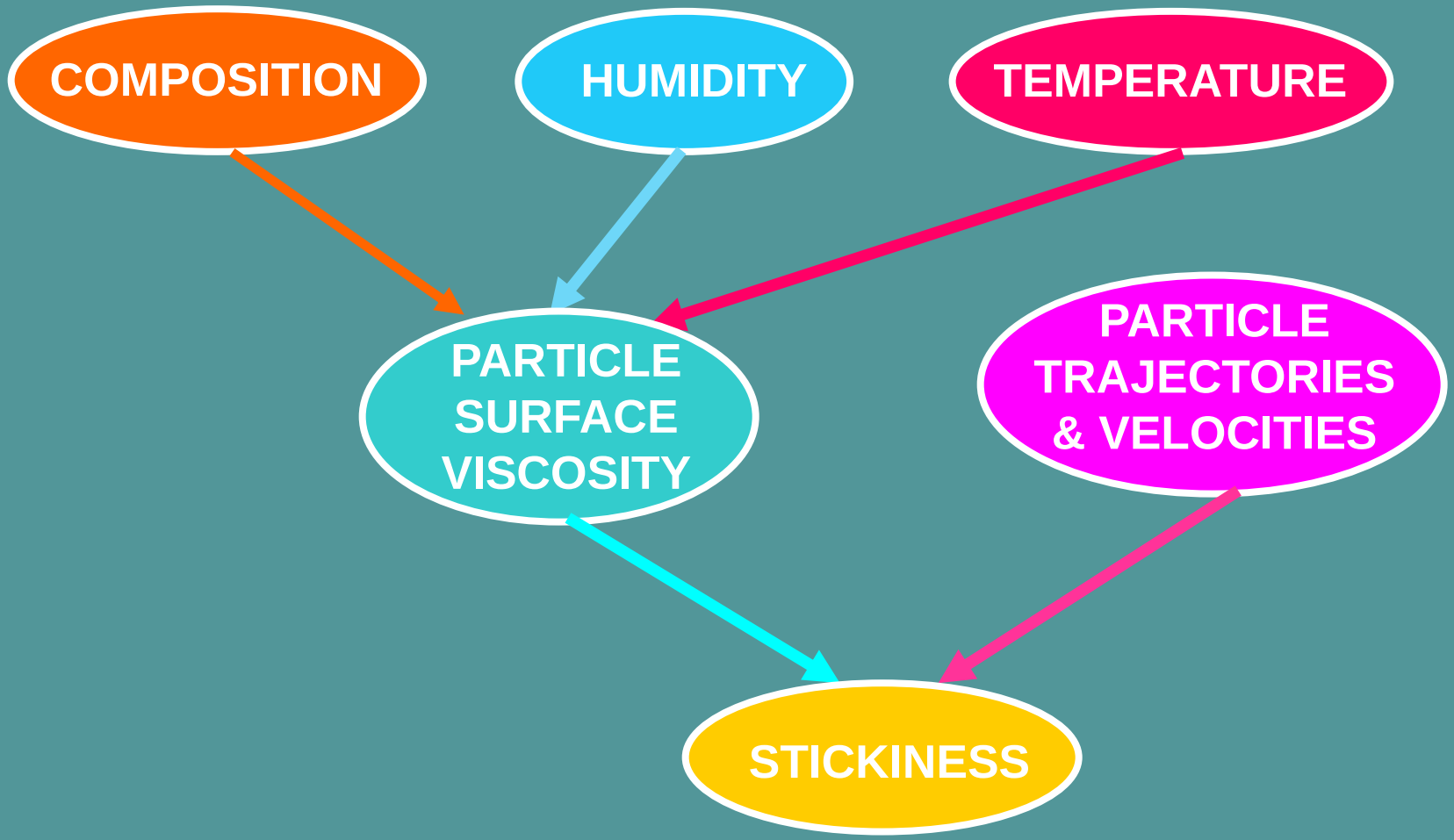
How Composition Affects Processing

The Stickiness Mechanism

In this demonstration grapes with a high moisture content are compared with glass marbles with zero moisture

How Composition Affects Processing

The Stickiness Mechanism



How Composition Affects Processing

Insights from the 2016 Dublin IDF Parallel Symposium

Donal O'Callaghan et al.

- surface fat, protein, carbohydrate are different from their bulk values for MPCs

Aoife Buggy

- alpha lactalbumin content affects viscosity in liquid and drying states

Sean Hogan & D O'Callaghan

- stickiness measurement and the way the drying process changes the surface composition from the bulk values

Romain Jeantet

- Surface composition affects particle morphology

How Composition Affects Processing

Insights from the 2016 Dublin IDF Parallel Symposium

Compositional changes affect the surface composition of the drying powder particles.

This changes the viscosity of the surface.

This affects the powder stickiness.

This requires changes to the dryer operating conditions to maintain trouble-free operation.

This may change the production rate.

How Composition Affects Processing

Powder Stickiness

Typically the surface content of protein and fat is higher than the bulk content while the surface content of carbohydrates is lower than the bulk.

This means that changes to the bulk composition will have different effects on the surface composition and therefore on the powder stickiness.

How Composition Affects Processing

The Problem:

Management have decided to change the product formulation on a nutritional or specialty powder already in production.

The Engineer's Approach

Find the minimum information necessary to decide in which direction and how far to change the dryer operating parameters.

Assumptions

- The dryer is already making the product acceptably with the original composition.
- It is not possible to run an exhaustive series of trials.

How Composition Affects Processing

The Information Required

The main problem boils down to changing the drying conditions to restore the surface viscosity of the drying particles of the new powder to that of the old.

Composition changes may include:

- Substituting harder or softer fats
- Adding FOS or GOS
- Hydrolysing proteins
- Adding or removing organic acids

How Composition Affects Processing

The Information Required

Ask these questions of each change:

- Will the change increase or decrease the amount of the component expected to be exposed on the particle surface?
- Will this increase or decrease the surface viscosity at the current dryer outlet air temperature and relative humidity?

How Composition Affects Processing

Types of Powder

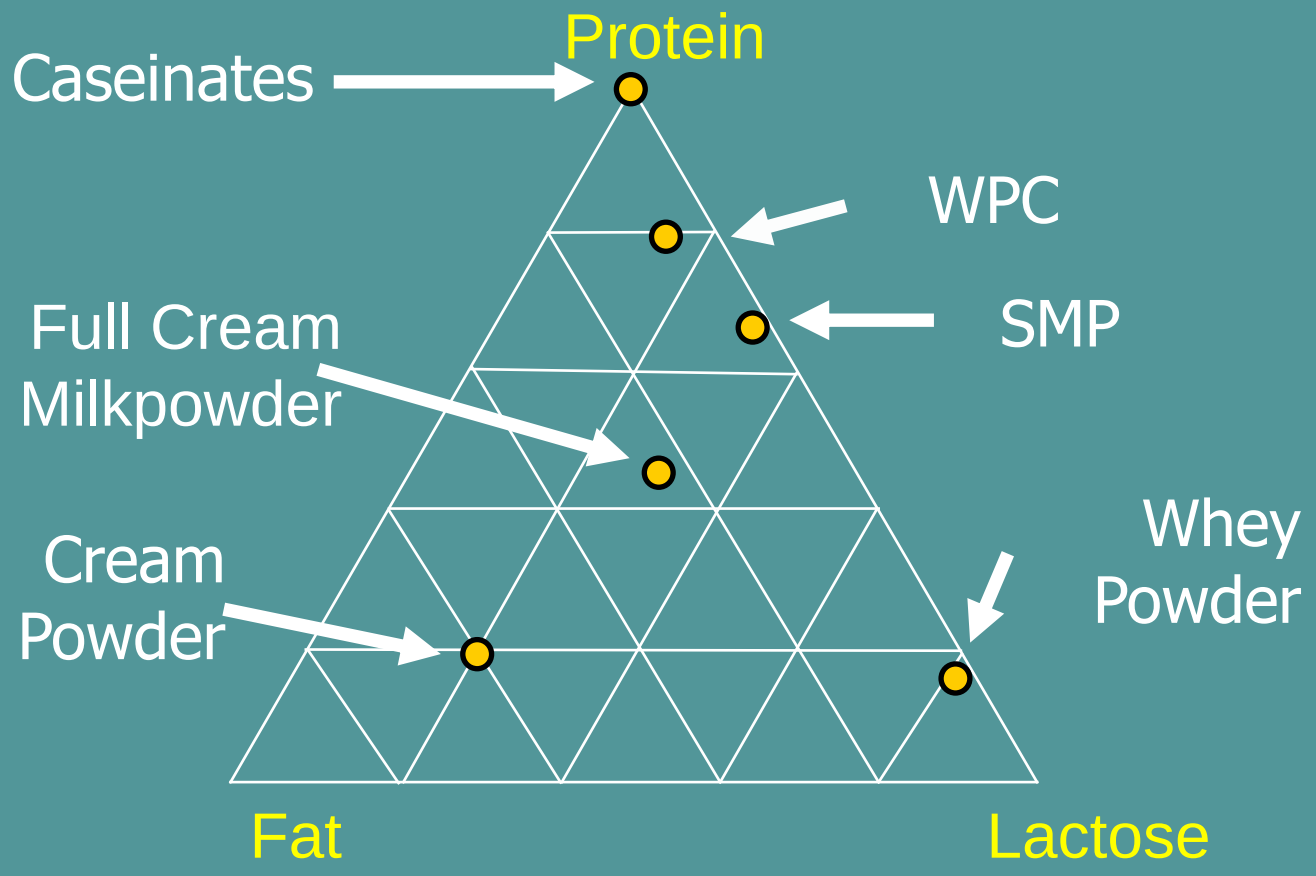
Products may be placed into four categories for the purposes of deciding on the most appropriate type of dryer for their manufacture:

Average composition	SMP, BMP, WMP
High Fat	cream, cheese powders
High Protein	caseinates, WPCs, WPIs, MPCs
High Lactose	whey powders, permeate powders, low protein powders, IF, FOF, GUMP

How Composition Affects Processing

Types of Powder

Selected powders are illustrated:

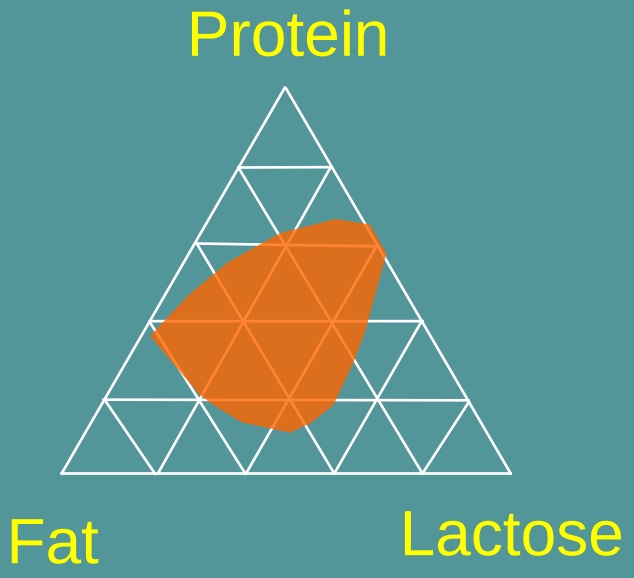


How Composition Affects Processing

Types of Powder

Average Composition Powders

- SMP
- BMP
- WMP



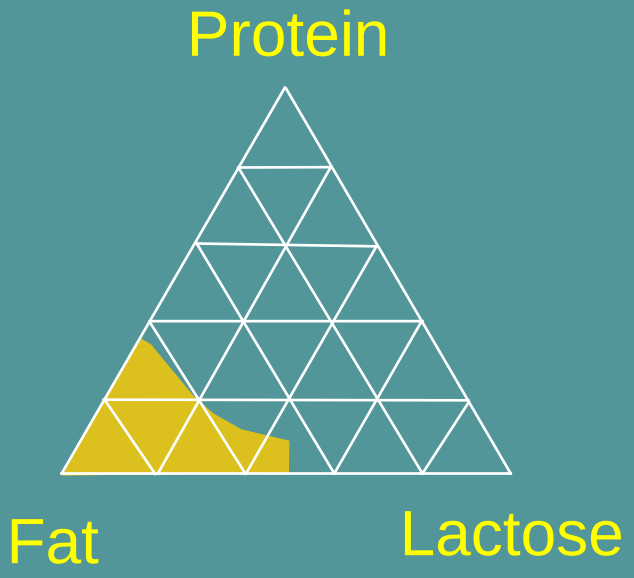
Powder stickiness depends on both outlet air temperature and outlet air relative humidity.

How Composition Affects Processing

Types of Powder

High Fat Powders

- cream powders
- cheese powders



These powders are easy to dry, but difficult to handle when hot, smearing over dryer surfaces, so fluid bed cooling is required.

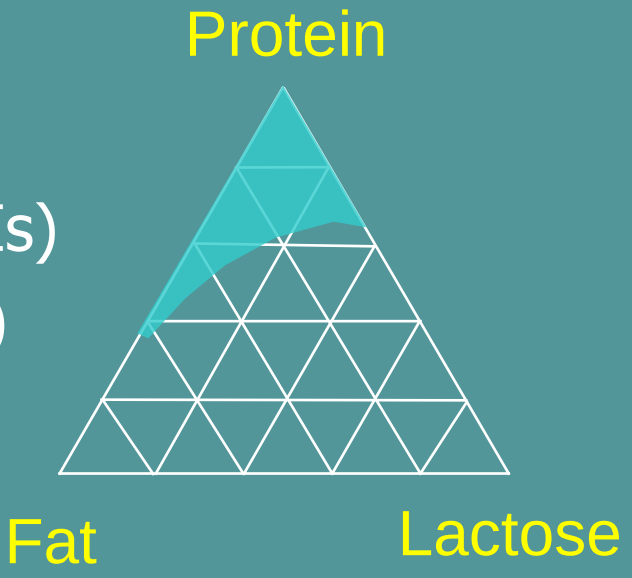
Temperature has more influence on stickiness than relative humidity.

How Composition Affects Processing

Types of Powder

High Protein Powders

- caseinates (sodium, calcium)
- whey protein powders (WPCs, WPIs)
- milk protein powders (MPCs, MPIs)



Protein binds water very tightly, so these products are difficult to dry to low moisture contents.

They are not particularly sticky, and they may be dried at low outlet temperature and high outlet relative humidity.

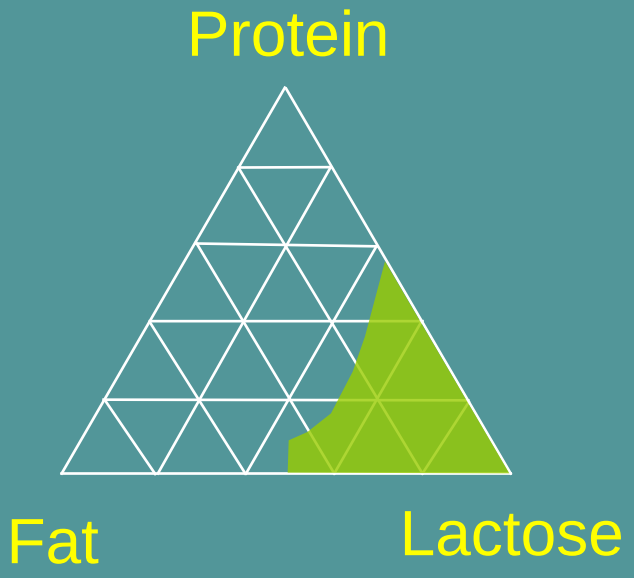
How Composition Affects Processing

Types of Powder

High Sugar Powders

- whey and permeate powders
- nutritional powders

These products must be dried at high outlet air temperature and low outlet air humidity.



How Composition Affects Processing

Changing the Dryer Operating Parameters

The main variables available to the dryer operator are:

- Inlet air temperature
  - this is used to increase or decrease the amount of evaporation and hence the outlet air absolute humidity and the dryer throughput.
- Outlet air temperature (by changing the liquid feed rate)
  - it changes the outlet air relative humidity and thus the carbohydrate stickiness of the powder
  - it changes the powder temperature and thus the fat stickiness of the powder.

How Composition Affects Processing

Changing the Dryer Operating Parameters

Other changes to the dryer operation may be possible, depending on the plant configuration:

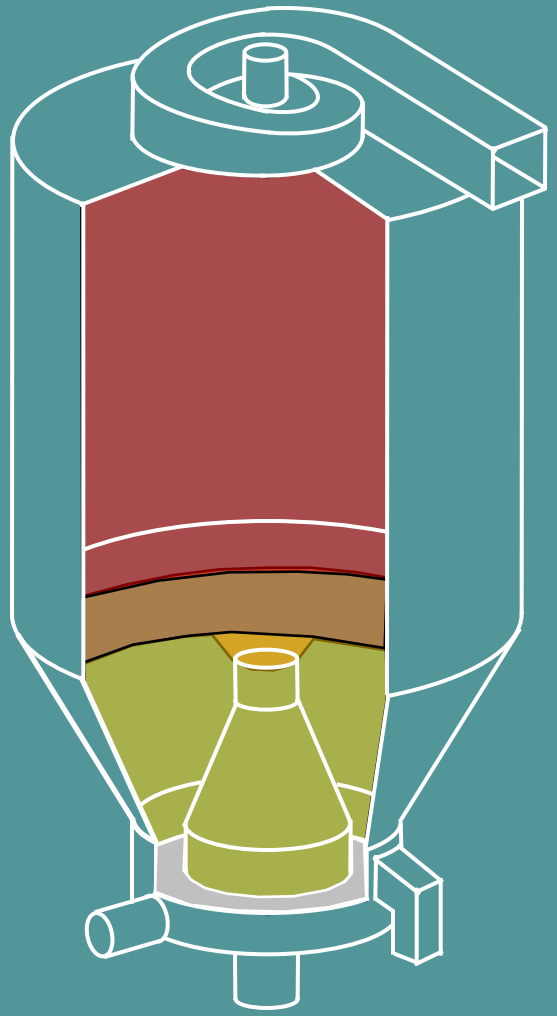
- Integrated fluid bed inlet air temperature
  - this is used to change the "dummy" outlet temperature for products that must be single stage dried and then cooled.
- False air addition
  - Cold false air helps cool high fat powders.
  - Hot false air reduces the relative humidity in exhaust ducts from external fluid beds on high sugar powders.

How Composition Affects Processing

"Dummy" Outlet Temperature

Compact dryer

If we pretend that all the heat energy used in evaporation comes from the primary air, and that the SFB air warms the air back up to the outlet temperature, we can calculate a dummy internal outlet temperature



How Composition Affects Processing

Dummy Outlet Temperature

The dummy outlet temperature is:

$$T_{dummy} = T_{outlet} + (G_{SFB}/G_{primary}) * (T_{outlet} - T_{SFB})$$

where:

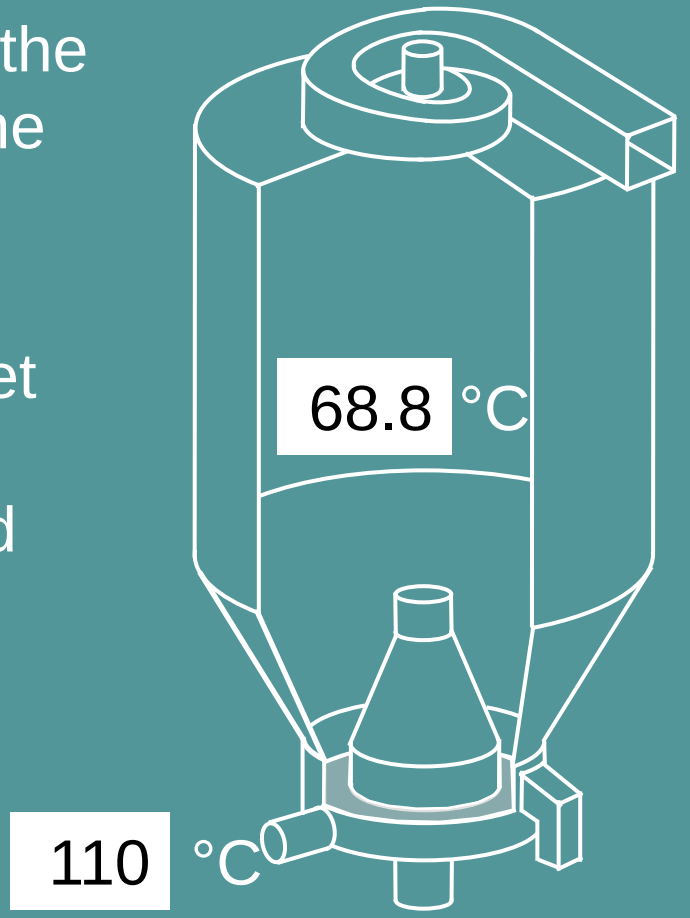
T_{outlet} = Measured outlet temperature (°C)
T_{SFB} = Measured SFB inlet air temperature (°C)
G_{SFB} = Measured SFB airflow (kg/h)
$G_{primary}$ = Measured primary airflow (kg/h)

How Composition Affects Processing

Dummy Outlet Temperature

This will help us understand the balance of drying between the two dryers sharing the same chamber

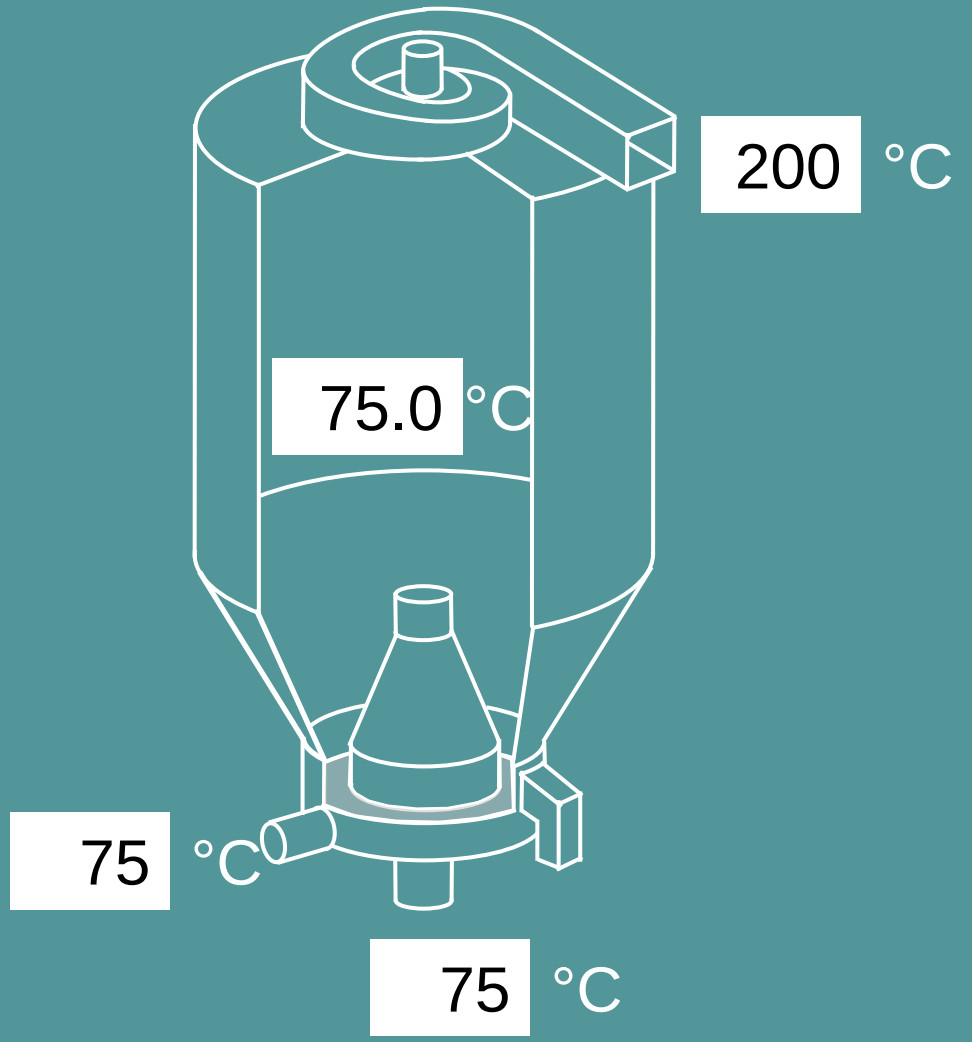
We can use the dummy outlet temperature to prevent the moisture getting too high and causing blockages



How Composition Affects Processing

Dummy Outlet Temperature

As the SFB temperature rises, the dummy outlet temperature falls



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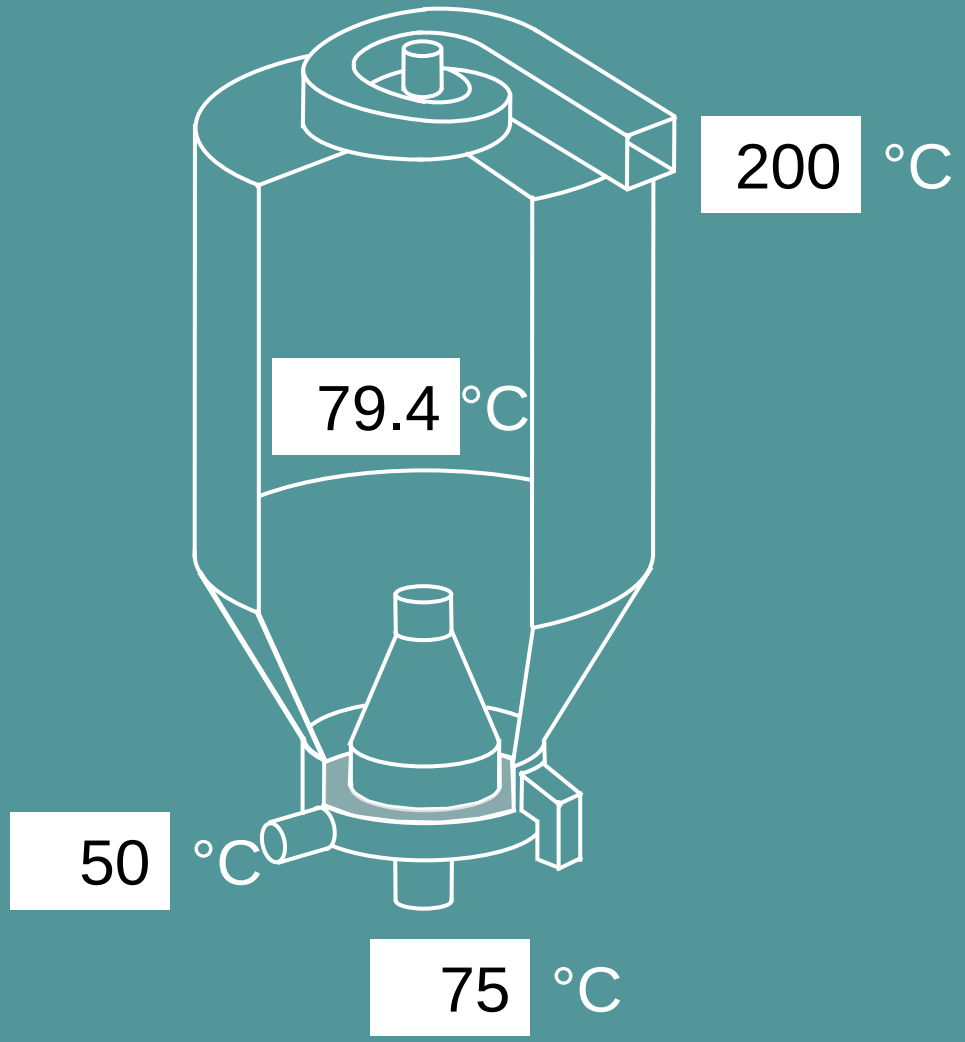


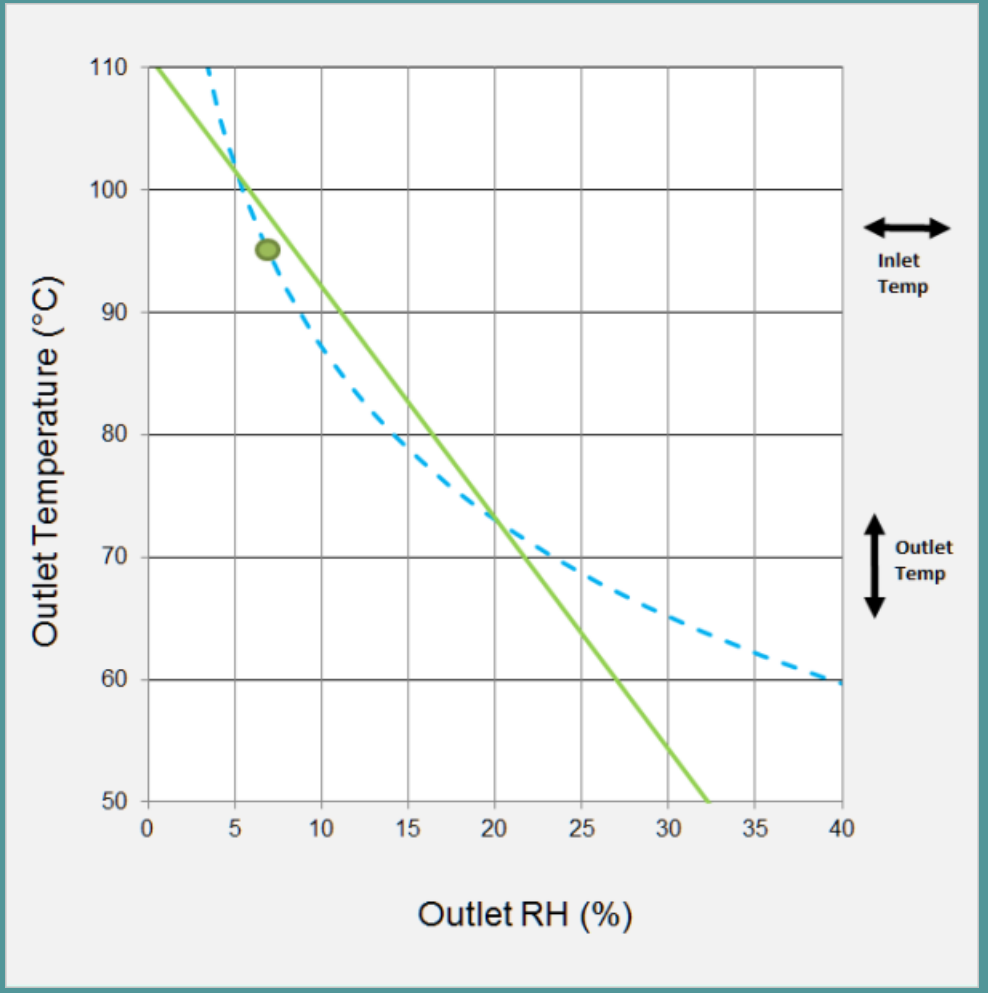
How Composition Affects Processing

Changing the Dryer Operating Parameters

A useful tool is a sticky plot which displays the outlet air temperature and relative humidity (RH).

The blue dashed line shows the movement of the RH as the outlet temperature is varied.

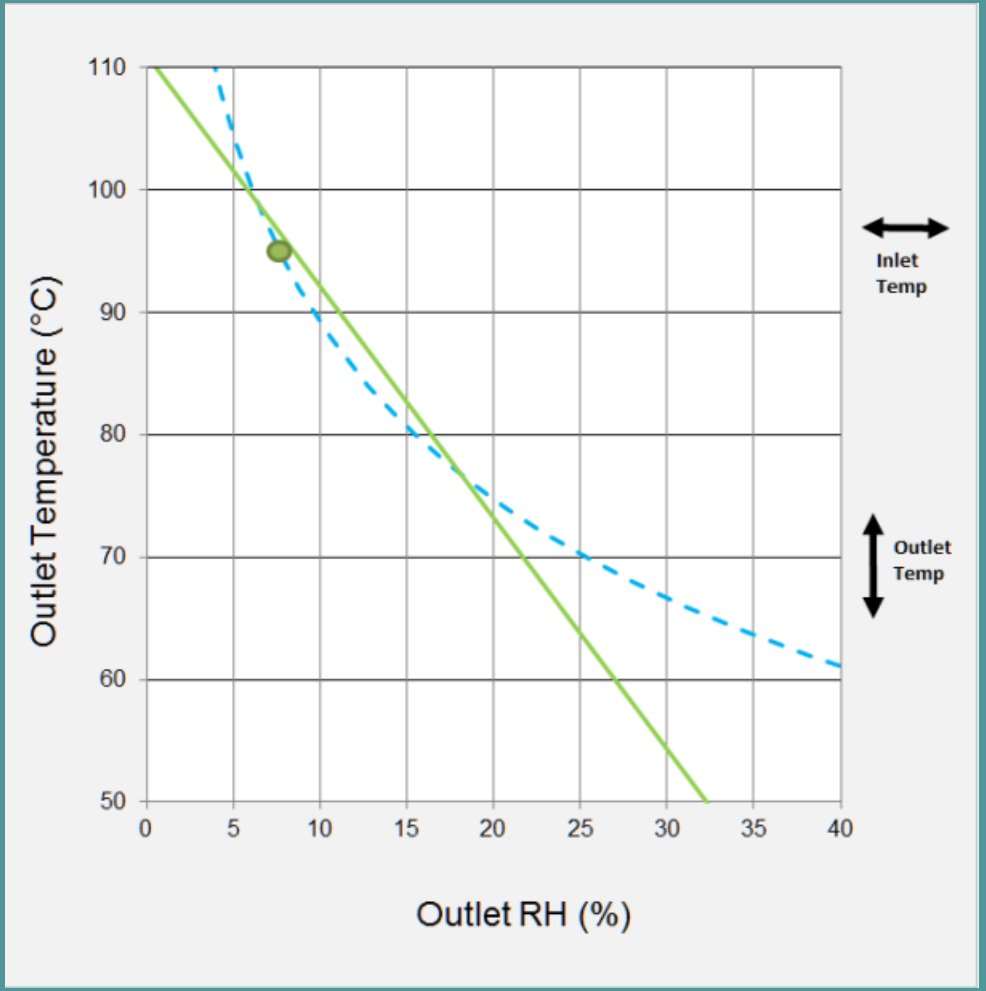
Below the green sticky line the powder will not stick.



How Composition Affects Processing

Changing the Dryer Operating Parameters

The blue dashed line moves to the right as the inlet air temperature is increased.



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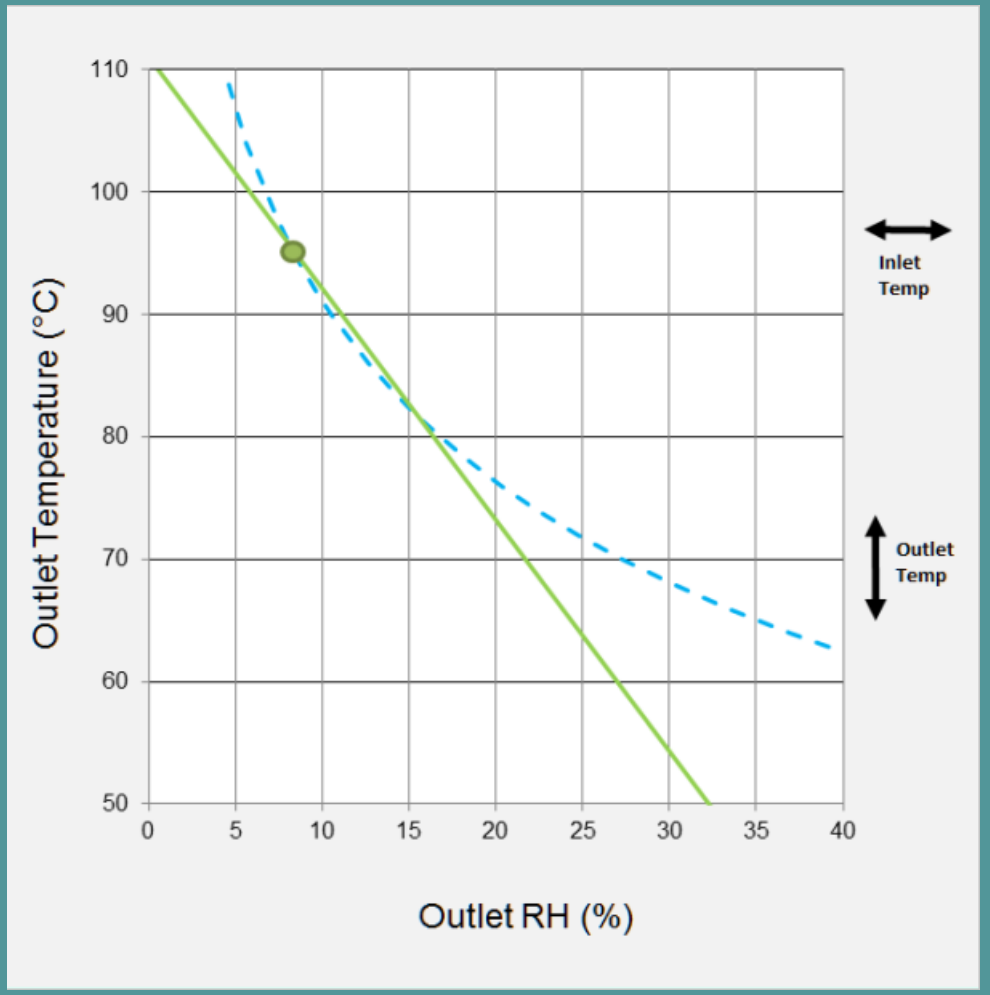
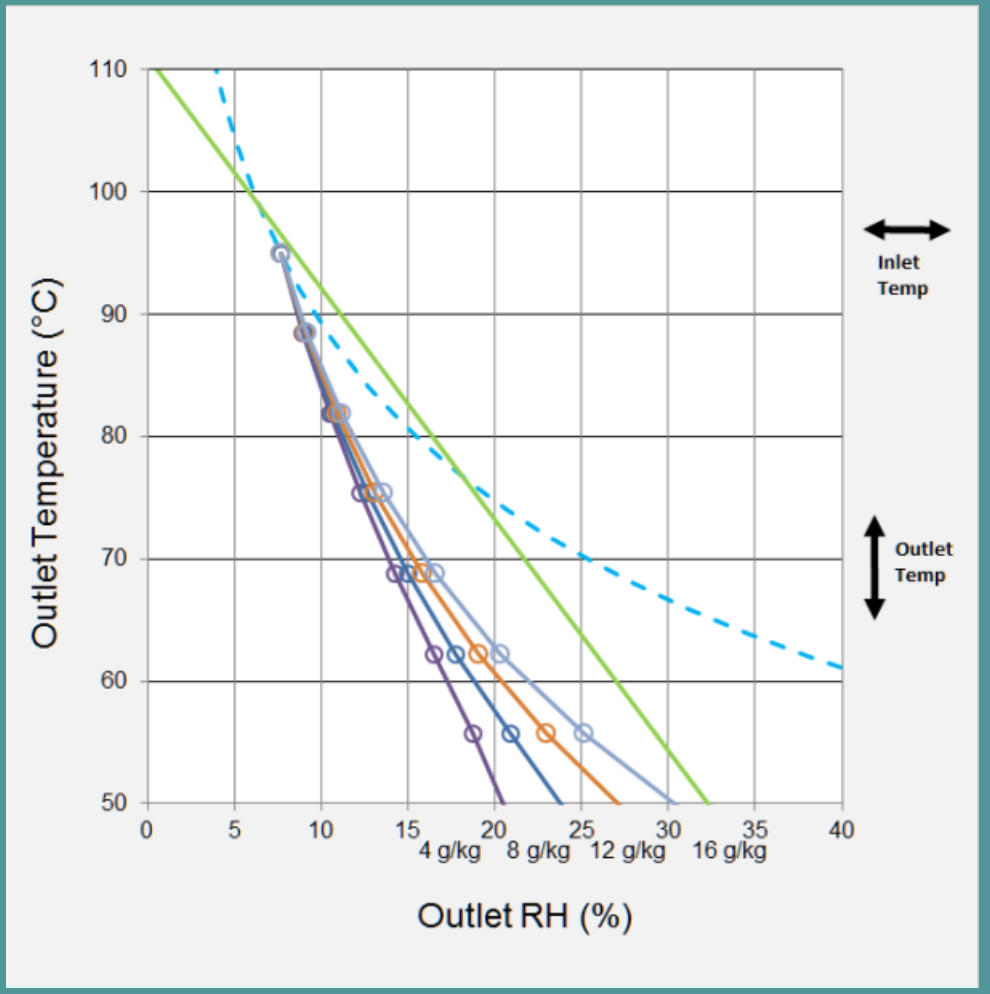


How Composition Affects Processing

Changing the Dryer Operating Parameters

If cold false air is added to the bottom of the chamber, or to the cyclones, the RH-temperature combination will get less sticky for high fat powders.

For high sugar powders adding cold air will cause stickiness.



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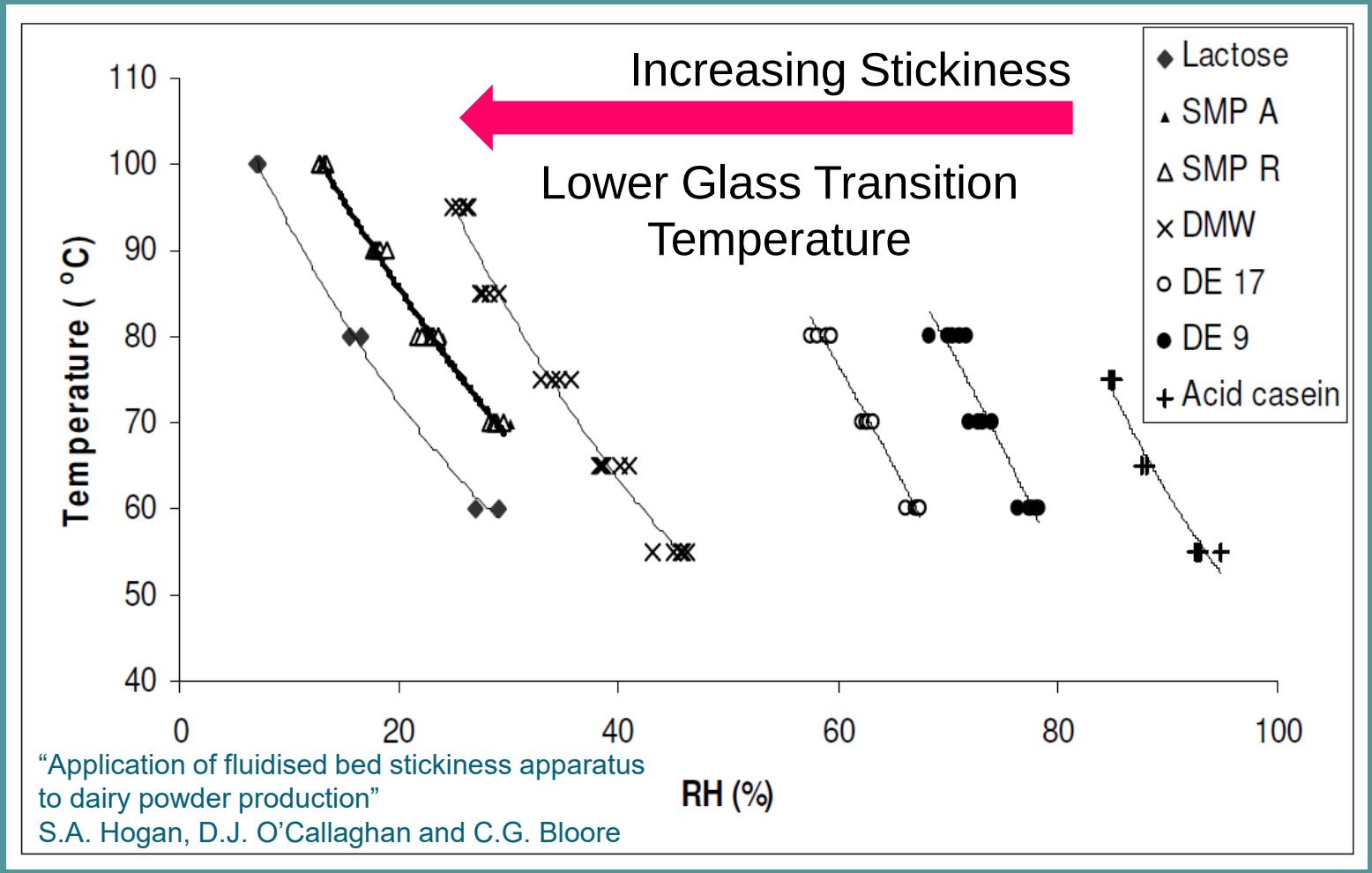
This approach has been built on Teagasc published work.



"Application of fluidised bed stickiness apparatus to dairy powder production"
S.A. Hogan, D.J. O'Callaghan and C.G. Bloore

How Composition Affects Processing

Conclusion

There are several practical tools available to estimate the direction and extent of changes to dryer operating parameters required to compensate for changes in product composition.

Making “minor” changes to a product formulation will often necessitate changes in processing variables and may have unwanted consequences for product throughput.

It is helpful if proposed changes are discussed with plant staff before being adopted!

Thank you all for your attention.