Powder Shear Cell: Influence of Humidity on Powder Characteristics of Pharmaceutical Powders

Relevant for: Pharmaceutical industry, Food industry, Chemical industry, Characterization of Powders, Powder Rheology, Powder Flow, Humidity, Shear Cell

Ambient conditions can strongly impact the behavior of many powders. In real life, bulk solids will show different flowability depending on the geographical location in which they are handled. While the impact of humidity in a saturated state is relatively simple to simulate by conditioning the sample in a climate chamber, it is more complex to depict the dynamic process which actually takes place in reality. The Anton Paar powder shear cell was used to determine different powder properties/processes like flow behavior and caking at a wide range of relative humidity (7% to 95%). A pharmaceutical hot drink powder was characterized, underlining the importance of considering ambient moisture when designing a process. Taking into account ambient humidity can prevent many problems in products and processes.

Figure 1: Rheometer equipped with powder shear cell and temperature and humidity option.

1 Introduction

Ambient conditions impact the behavior of many powders. Bulk solids show different flowability depending on the geographical location and thus different environmental conditions, e.g. Boulder/Colorado (25°C, 35 %rH) vs. Manila (30°C, 80 %rH). The adjustment of a powder to its environmental conditions is a dynamic process which reaches saturation at a certain point. Apart from saturation, many powders exhibit a “sticky point” where a significant change in flow and adhesion behavior is reported. [1]

The combination of a ring shear cell with a convection temperature device and humidity control within a rheometer enables the investigation of the influence of different humidity-temperature-combinations directly before and during the powder characterization. It is not necessary to expose the sample to conditions differing from the aimed ones by transferring it from an environmental chamber to the measuring device, nor will it change its moisture content (dry or moisten) during the measurement. In general granular media exposed to ambient moisture tends to become more cohesive (though exceptions at high normal stress exist). This is due to a variety of different mechanisms, chief among these is liquid bridging between grains, swelling of the grains themselves, formation of adhesive films on the grain surface, or in case of a declining cohesive behavior a “lubrication” of the interstitials between grains. [2]

The sample investigated is a pharmaceutical cold and flu hot drink which contains high amounts of vitamin C; citric acid, sugar and several pharmaceutically active materials. Beforehand it showed a tendency to cake and time consolidate, highly aggravated by moisture. We believe this to be a result of a partial dissolution in condensed water as Groen et al. suggests [1] for a similar sample (pure citric acid). When the sample is dried afterwards, the citric acid precipitates and forms solid bridges between the grains leading to very strong bonds between the remaining granules, making flow nearly impossible. While problematic for storage, this behavior is actually desired as the drink should readily dissolve in water for its application. A very similar “sticky point” to the pure substance is expected because of the large amount of citric acid in the pharmaceutical cold and flu hot drink.

Additionally, it is consistently reported that moisture leads to a strong increase in caking behavior, especially when cyclically applied (i.e. drying and wetting the powder repeatedly).

The influence of these phenomena on the behavior of pharmaceutical or food powders is usually not desired, as they often lead to clumps and knots forming and the powder itself becoming hard to process. In extreme examples this can lead to a solid lump of material forming, making further use impossible.

Therefore we aim to describe changes in powder characteristics after exposure to four different relative humidity levels and the difference between consolidated and non-consolidated samples.

2 Sample Preparation and Experimental

An Anton Paar Modular Compact Rheometer (MCR) equipped with a convection temperature device (CTD), a humidity generator and a powder shear cell was used to run the measurements, investigating powder characteristics and caking of a pharmaceutical cold and flu hot drink powder.

To ensure the same starting conditions concerning water content of the sample, the powder was stored in an oven at 70°C before use.

2.1 Influence of Humidity on Flowability

The sample was loaded into the ring shear cell which was placed within the CTD on the MCR and exposed to a defined relative humidity for 4 hours at 30°C (see Table 1). Each preshearing step was accompanied by multiple shear-to-failure steps (for more details on shear cell measurements please refer to the application report “An introduction to powder rheology”).

Sample preparation – environmental conditions	Sample measurement – preshear normal stresses
7 %rH (4 h, 30°C)	3 kPa / 6 kPa / 9 kPa / 12 kPa
35 %rH (4 h, 30°C)	3 kPa / 6 kPa / 9 kPa / 12 kPa
65 %rH (4 h, 30°C)	3 kPa / 6 kPa / 9 kPa / 12 kPa
95 %rH (4 h, 30°C)	3 kPa / 6 kPa / 9 kPa / 12 kPa

Table 1: Overview of sample preparations and measurements carried out for testing the influence of humidity on flowability.

2.2 Influence of Humidity on Caking

In order to study the effect of humidity on time consolidation (caking), three different tests were carried out. First the sample was presheared at 6 kPa. Then the sample was consolidated at 6 kPa at 30°C for 4 hours at varying humidity conditions (see Table 2) before a shear-to-failure was carried out.

Step 1 preparation	Step 2 – conditioning / caking	Step 3 – measurement
Preshear	4 h at 7 %rH (30°C)	Shear-to-failure
Preshear	4 h at 95 %rH (30°C)	Shear-to-failure
Preshear	2 h at 95 %rH (30°C) 2 h at 7 %rH (30°C)	Shear-to-failure

Table 2: Overview of measuring steps of the different measurements carried out for caking tests.

3 Results

3.1 Influence of Humidity on Flowability

The hot drink powder was exposed to four different relative humidities between 7 %rH and 95 %rH and then investigated at 3 kPa, 6 kPa, 9 kPa and 12 kPa (see Table 1).

Exemplarily, Figure 2 shows the shearing diagram depicting shear normal stress and shear stress over time for the sample after conditioning at 7 %rH and preshearing at 6 kPa. The preshearing intervals can be easily recognized by the constant preset of 6 kPa normal stress (gray curve). In-between, shear-to-failure was carried out at different normal stresses. Those runs at different normal stresses are necessary in order to analyze the powder with a Mohr’s stress diagram.

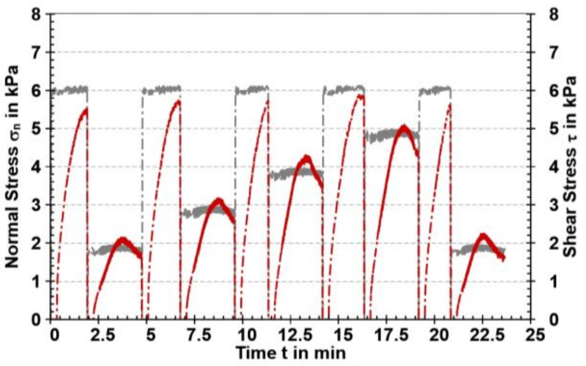

Figure 2: Shear diagram of preshearing at 6 kPa and intermediate shear phases (shear-to-failure) with different normal stresses. This was done at 7 %rH. The normal stress σ_n is in gray while the red curve depicts the shear stress τ.

Figure 3 shows the Mohr’s stress diagram for the measurement at 7 %rH and preshear normal stress of 6 kPa, the shear stress is shown over the normal stress. This is always created for one preshear stress and can be used to evaluate powder properties like angle of internal friction and many more.

The maximum shear stress during preshear and the maximum shear stress in each individual shear sequence in the Mohr´s stress diagram give the yield locus function. Based on this yield locus function and the preshear maximum the two Mohr circles are drawn.

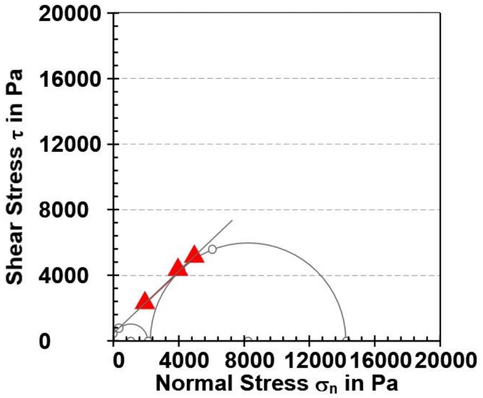

Figure 3: Mohr's stress diagram for the preshearing at 6 kPa of the sample measured at 7 %rH.

With increasing normal stress the Mohr circles also increase. This is displayed in Figure 4 for the sample at 7% humidity where the yield locus function and Mohr circles are shown for measurements at preshear normal stress of 3, 6, 9 and 12 kPa.

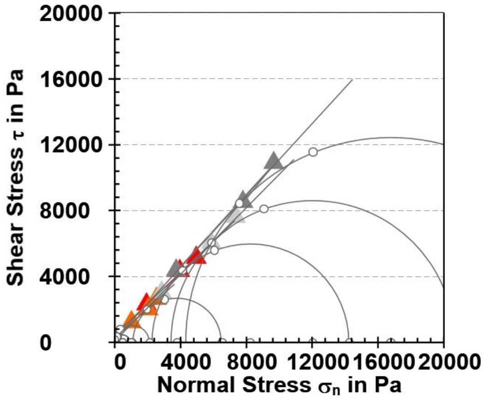

Figure 4: Mohr's stress diagram for the sample at 7 %rH, showing the measurement at 3 kPa (orange), 6 kPa (red), 9 kPa (light grey) and 12 kPa (dark grey).

In the next part, the measurements at different relative humidity levels were compared. Figure 5 depicts the second shear-to-failure phase of the measurement at 6 kPa for 7, 35, 65 and 95 %rH. While only a minimal change can be observed between 7 and 35 %rH, the sample starts to show a significant change at higher relative humidity levels. The maximum of the shear stress increases slightly, but more notably the slope of shear stress decreases with higher relative humidity. This means that in addition to the static behavior tracked by the preshear shear maxima the dynamic behavior of the powder is also strongly affected.

Between 65 and 95 %rH there is a further shift in the curve and a very strong increase in shear stress.

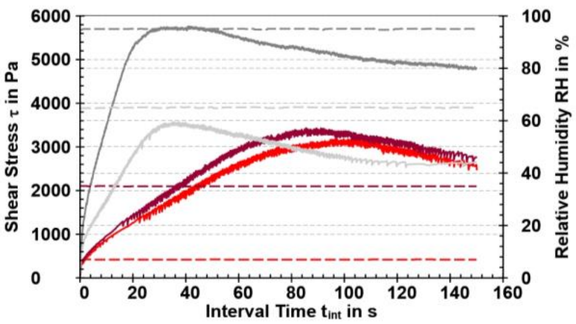

Figure 5: The second shear-to-failure phase after 6 kPa preshearing for the samples at 7% (light red), 35% (dark red), 65% (light grey) and at 95% (dark grey) relative humidity. The dashed lines show the relative humidity.

In the Mohr´s stress diagram (see Figure 6) of the measurements described in Figure 5, the humidities between 7 %rH and 65 %rH do not display any outstanding differences. Only the measurement at 95 %rH has significantly higher yield locus function.

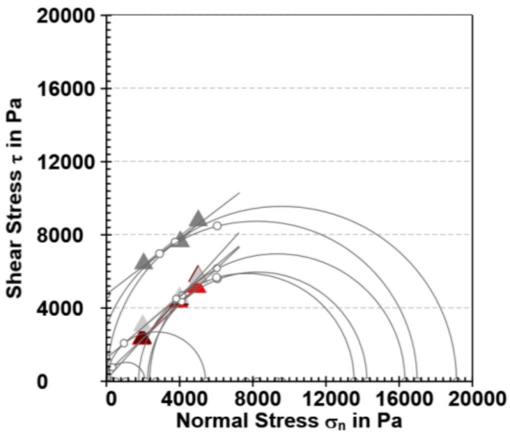

Figure 6: Mohr stress diagram of the measurement at 6 kPa preshear normal stress of the samples at 7 %rH (light red), 35 %rH (dark red), 65 %rH (light grey) and at 95 %rH (dark grey), of the measurement at 6 kPa preshear normal stress.

From the Mohr's stress diagram the coefficient of flowability can be evaluated from the major principal stress and the unconfined yield strength for each preshear normal stress. This step is also done automatically in the RheoCompass™ software. The flowability coefficient is presented in the ff_c diagram (Figure 7) where the unconfined yield strength is depicted over the major principle stress. This diagram now includes the measurements for preshear normal stress of 3 kPa, 6 kPa, 9 kPa, 12 kPa. The data for the additional normal stresses was retrieved exactly as for the 6 kPa shear normal stress (as explained above).

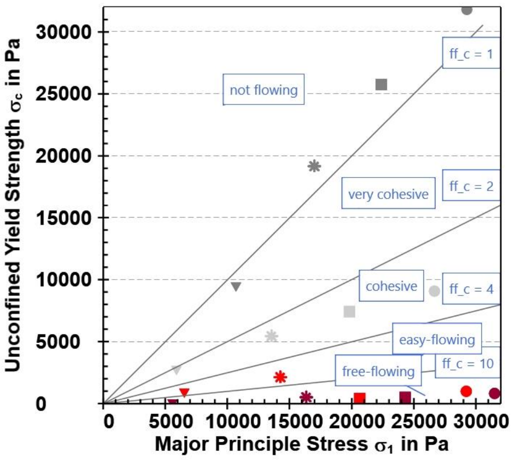

Figure 7: ff_c diagram showing the flowability of the samples at 7 %rH (light red), 35 %rH (dark red), 65 %rH (light grey) and at 95 %rH (dark grey) for a preshear normal stress of 3 kPa (triangle), 6 kPa (star), 9 kPa (square) and 12 kPa (circle).

While the hot drink powder is – independently of the applied stress during preshearing – free flowing/easy flowing when exposed to low relative humidity (7 %rH and 35 rH%), the powder becomes cohesive when exposed to 65 %rH (see Figure 7). When further increasing the relative humidity to 95 %rH the powder properties change to very cohesive for low stresses and turn to not flowing for increasing stresses, thus behaving more like a solid. When comparing these values with the sticky point measurement from Groen et. al. which estimates the sticky point of citric acid at 30°C at 55% rH the results show a very good agreement.

A further coefficient gained from the Mohr's stress diagram is shown in Table 3. The effective angle of internal friction φ_e is a measure of the internal friction at steady-state flow and depends predominantly on interparticle adhesive and frictional forces. φ_e increases with the relative humidity, but could not be determined for 95 %rH because of the toughness that the sample exhibited afterwards.

Relative humidity	Effective angle of internal friction φ_e
7%	46.77°
35%	48.49°
65%	50.56°
95%	-*

*Table 3: Effective angle of internal friction compared at 6 kPa preshear normal stress. (*the sample at 95% was so solid that φ_e could not be determined)*

3.2 Influence of Humidity on Caking

The samples were presheared and measured at 6 kPa and then exposed to certain humidity levels for 4 h while consolidating at 6 kPa. The samples were then sheared-to-failure. Three different humidity conditions were tested, as described in Table 2.

The Mohr´s stress diagram for those three tests are displayed in Figure 8. The first measurement (4 h at 7 %rH, light red in Figure 8) does not show a significant change compared to the previous measurement (blue). The same is the case for the second measurement (4 h at 95 %rH, dark gray). The third measurement consisted of a moistening and re-drying step - 2 h at 95 %rH followed by 2 h at 7 %rH (green in Figure 8). In contrast to the previous measurements this sample shows an extreme change, with a preshear stress much larger than observed before, even at 95 %rH.

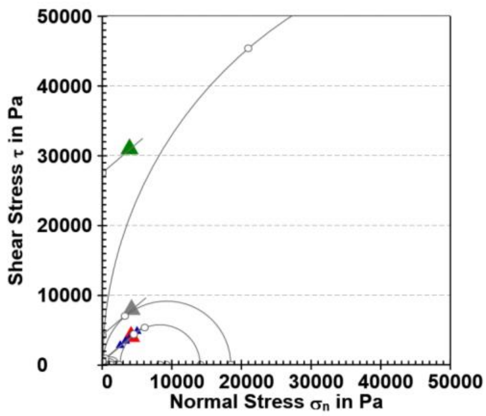

Figure 8: Mohr stress diagram of the samples at 7 %rH (light red), 95 %rH (dark grey) and 95/7 %rH (green) after 4 h of consolidation at 6 kPa. The blue triangles represent the sample before the 4 h consolidation.

Similar trends are observed in the ff_c diagram in Figure 9:

<u>7 %rH</u>: The red star is without time consolidation, while the red square is with 4 h time consolidation. Both show very similar values and an easy-flowing behavior.

<u>95 %rH:</u> The gray star without time consolidation, while the gray square is with 4 h time consolidation. Again both show very similar values and a not-flowing behavior.

<u>95 %rH / 7 %rH:</u> The green square shows the ff_c of the sample after moistening (2 h) and re-drying (2 h) while being consolidated. The change from very humid to very dry during consolidation transformed the powder sample into a solid. This is reflected in the extremely high unconfined yield strength σ_c of 119.4

kPa, which equals an ff_c coefficient of 0.12 at a major principal stress σ_1 of 14.1 kPa.

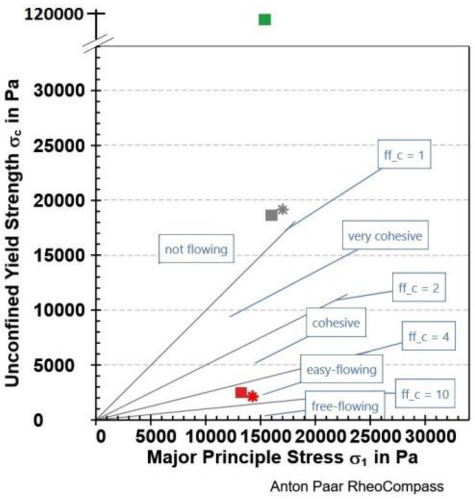

Figure 9: ff_c diagram of the samples at different humidity levels without and with 4 h time-consolidation at 6 kPa (all measured with preashearing at 6 kPa). Not time-consolidated samples: 7 %rH (red star) and 95 %rH (grey star); Time-consolidated samples: 4 h at 7 %rH (red square), 4 h at 95 %rH (grey square) and 2h each at 95 / 7 %rH (green square).

4 Conclusions

The investigated pharmaceutical cold and flu hot drink showed a change in its characteristics in dependence of the environmental humidity. The sample after time-consolidation at 6 kPa did not greatly differ from the sample measured under normal conditions, meaning that the sample (when in a dry environment) does not tend to cake. An especially critical factor was revealed to be drying after the exposure to high relative humidity. Here the sample partially dissolved in a moist environment and formed a hard conglomerate after drying. Furthermore the measurements showed a good agreement on the sticky point measurements on citric acid found in literature [1].

This report showed that the Anton Paar powder shear cell in combination with its humidity option enables the investigation of powder behavior in a wide range of relative humidity levels. This can be done with or without applying consolidation. This allows measuring the impact ambient/environmental conditions can have during processing and storage. This information enables the accurate planning of processes and plant manufacturing but also shows the impact that storage under improper condition can have on product lifetime as well as its usability.

5 References

1. Groen, Johan C., et al. "Real-time in-situ Rheological Assessment of Sticky Point Temperature and Humidity of Powdered Products." *KONA Powder and Particle Journal* (2020): 2020006.

2. Nokhodchi, Ali. "Effect of moisture on compaction and compression." *Pharm. Tech* 6 (2005): 46-66.

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