

# How temperature and humidity affect hygroscopic material flow behavior

Johnselvakumar Lawrence

K-State Bulk Solids Innovation Center

Material flow behavior is affected during storage and processing by ambient temperature and humidity fluctuations. These fluctuations can result in material caking, bridging, and flowability issues that can cause equipment downtime and other process slowdowns. This article focuses on the relationship between a hygroscopic bulk solid material's moisture level and how ambient temperature and relative humidity impact that material's flowability.

**B**ulk solids processing frequently requires material transfer via pneumatic conveying, gravity, or other method from outdoor storage to an indoor process or, conversely, from a process to outdoor storage. As a material is exposed to the temperature and humidity level differences in these two environments, the material's flowability can be affected, leading to line plugging and material flow issues. To avoid these problems, operators can benefit from learning how important the moisture sorption characteristics of a material can be to maintaining reliable material flow.

## Understanding material moisture content

Many powder and bulk solids such as chemical, mineral, plastic, pharmaceutical, or food materials absorb moisture based on the material's sorption characteristics. Two important terms to understand when considering a material's moisture content are *adsorption* and *desorption*. Adsorption is adhesion of an extremely thin layer of liquid molecules to the surface of a particle. Desorption means "to remove" and is the reverse action to adsorption.

For bulk solids produced from plants and trees, such as grain, feed, wood chips, and granules (biological in nature), the moisture adsorption and desorption behaviors are called the material's *equilibrium moisture content (EMC)* characteristics. EMC describes a

hygroscopic material's moisture content (expressed as a percentage) at a given temperature and relative humidity at the point when the vapor pressure of the water held by the material's particles becomes equal to the water vapor pressure of the surrounding air. When a material is at EMC, there's no moisture adsorption or desorption. In some processes, a material will be kept at its EMC for a given temperature and relative humidity to maintain quality because at EMC an operator can be assured that the material's flow and sorption characteristics won't change and impact processing or, in some cases, the final product. One moisture-sensitive material, popcorn, achieves the best popping quality at a 13.5 percent moisture content. Finding the temperature and relative humidity values to maintain the popcorn kernels at a 13.5 percent EMC means that the popcorn's moisture content won't fluctuate above or below this percentage, which would greatly reduce popping quality.

The surrounding environment's temperature and relative humidity, which are considered separately from the material's properties, are major factors that affect the material's EMC. These two variables will change during the course of a day and when a material moves from the outside to the inside of a plant — and vice versa. A material absorbs or desorbs moisture based on the current temperature and relative humidity, meaning that EMC fluctuations can be frequent. Generally, materials experience a higher temperature and lower relative humidity during the day and a lower temperature and higher relative humidity at night. During a high EMC period (low temperature and high relative humidity), material can absorb moisture from the environment. This increase in moisture content significantly affects the material's flow properties. Likewise, during a low EMC period (high temperature and low relative humidity), a material may desorb moisture. This decrease in moisture content eventually increases the material's static electricity, which can also impact how the material flows, and should be monitored as part of combustible dust safety requirements in a plant.

For nonbiological materials like chemicals, the moisture sorption characteristics are represented by *critical relative humidity (CRH)*. The CRH of any chemical is the relative humidity of the environment

and the particular temperature at which material begins to absorb moisture from the atmosphere. Below CRH, a material will stop absorbing moisture. For example, calcium nitrate and potassium chloride have a 46.7 and 84.0 percent CRH, respectively, at a 30°C temperature.<sup>1</sup> If the temperature changes, the CRH also changes.

### Comparing adsorption and desorption

Understanding the moisture sorption characteristics of your material under different temperatures and relative humidity levels is important as those characteristics relate directly to a material's flow properties. As previously stated, adsorption and desorption are two types of moisture sorption characteristics. When testing a material's moisture levels during absorption and desorption, the resulting graphed data show that the desorption characteristic curve is always greater than the adsorption curve, and the difference in these curves is called *hysteresis*. Hysteresis occurs due to a slowing effect when the forces acting on a particle are changed.

For example, the moisture sorption characteristics of rice bran are shown in Figure 1.<sup>2</sup> The graph shows that the moisture released during desorption and the moisture added during adsorption aren't the same. This could be because the kinetics of filling moisture in the material's capillary pores are different than the kinetics of removing the moisture from the material.

When a material absorbs or adsorbs moisture from the environment, that material's flowability decreases because the increased thickness of the material's adsorbed liquid layer increases the strength of liquid (capillary) bridges developed between particles. This liquid-bridging process continues during storage or at stagnation points in a pipeline, which can lead to

caking or crust formation. Similarly, adsorbed moisture increases the material's cohesiveness because of the increase in surface tension. In some cases, particle interlocking due to surface roughness can be reduced by an increase in moisture. In the rice bran's case, the particles' angle of internal friction increases with an increase in moisture content. In some other cases, interlocking due to surface roughness can be reduced by an increase in moisture.

### Determining adhesion forces

For dry bulk solids, particle adhesion happens as a result of van der Waals' forces, electrostatic forces, and electrical forces.<sup>3</sup> For wet bulk solids, the particle adhesion happens as a result of liquid bridges between particles. The total force of adhesion acting on the particles is a sum of all these forces and can be determined by this formula:<sup>4</sup>

$$F_{ab} = F_v + F_c + F_e + F_{es}$$

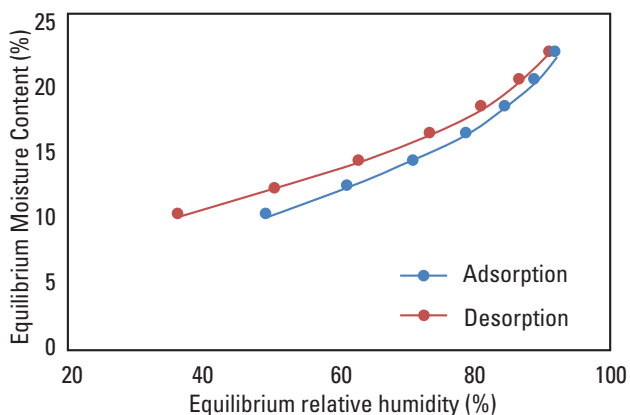
In this formula,  $F_{ab}$  is the force of adhesion;

$F_v$  is the Lifshitz-van der Waals' force;  $F_c$  is the capillary force;  $F_e$  is the electrical force; and  $F_{es}$  is the electrostatic (Coulomb) force.

The percentage of water in the material determines the strength of capillary forces. When the ambient air's relative humidity is above 65 percent, capillary force within the particles dominates over all other forces within the material. That is, moisture's effect on material flowability dominates. In a hopper, this could cause arching and block material flow. Therefore, by monitoring the environment's relative humidity and temperature to keep the relative humidity below 65 percent, you'll be able to control the capillary force, which can help prevent other flow problems, including caking, bridging, and ratholing caused by adhesion.

**Figure 1**

#### Adsorption and desorption curves of rice bran



### Examining two typical material moisture problems

Here are two examples of how material moisture problems can occur in your plant and how to resolve the issue:

- Wheat flour can hold significant amounts of moisture. However, when it's pneumatically conveyed into a silo, the positive-displacement pressure blower's high temperature may cause moisture to desorb, causing flow issues, wetness, and mold in the silo. The problem can be avoided by cooling the conveying air and using a vacuum instead of a pressure system because vacuum has a lower operating temperature. You could also add a blanket of dry air to the silo with a desiccant dryer.
- When pneumatically conveying hygroscopic material, such as wheat flour, the material absorbs moisture from the environment if the ambient air's

relative humidity is greater than the material's relative humidity. This relative humidity imbalance will change the material's flow properties and chemical reactions and create line buildup. Attaching a desiccant or refrigerant dryer to the conveying line's air inlet is a common practice to reduce high-relative-humidity conveying air. The conveying lines are insulated to avoid condensation problems because of temperature differences between the conveying air and ambient air. The temperature change affects the material's EMC, and the EMC subsequently affects the material's flow properties. **PBE**

### References

1. J. Richard Adam and Albert R. Merz, "Hygroscopicity of fertilizer materials and mixtures," *Industrial and Engineering Chemistry*, Vol. 21, Issue 4, 1929, pages 305-307.
2. *ASABE Standard D245.6: Moisture relationships of plant-based agricultural products*, American Society of Agricultural and Biological Engineering (ASABE), 2012. Available at [www.asabe.org](http://www.asabe.org).
3. Dietmar Schulze, *Powders and Bulk Solids: Behavior, Characterization, Storage and Flow*, Springer-Verlag Berlin Heidelberg, 2008.
4. Poj Kulvanich and P.J. Stewart, "Fundamental considerations in the measurement of adhesional forces between particles using the centrifuge method," *International Journal of Pharmaceutics*, Vol. 35, Issues 1-2, 1987, pages 111-120.

### For further reading

Find more information on material flow in articles listed under "Flow properties" and "Solids flow" in *Powder and Bulk Engineering's* article index in the December 2017 issue or the Article Archive on *PBE's* website, [www.powderbulk.com](http://www.powderbulk.com). (All articles listed in the archive are available for free download to registered users.)

---

**Johnselvakumar Lawrence** is research director at the K-State Bulk Solids Innovation Center ([jlawren@k-state.edu](mailto:jlawren@k-state.edu), 785-404-4918). He holds a PhD in agricultural and biological engineering from Purdue University, West Lafayette, IN, and an MS in agricultural processing and a BS in agricultural engineering from Tamil Nadu Agricultural University, Coimbatore, India.

**K-State Bulk Solids Innovation Center**  
**Salina, KS**  
**785-404-4918**  
**[bulk-solids.k-state.edu](http://bulk-solids.k-state.edu)**