Flow Properties of and Recommendations for Handling Polypropylene Powder

A sample of polypropylene powder was provided for testing. Cohesive strength, compressibility, and wall friction tests were performed at 20°C, under conditions that simulated continuous handling and handling after 24 hr storage at rest. From the test results, minimum hopper outlet dimensions for prevent obstructions to flow and recommended mass flow hopper angles were calculated.

Test results

Test results are summarized in Tables 1 through 3 and Figures 1 through 4.

Table 1
Cohesive Strength Test Results

Major Principal Stress (kPa)	Unconfined Yield Strength (kPa)	Unconfined Yield Strength after 24 hr Storage at Rest (kPa)	Effective Angle of Friction (deg)	Kinematic Angle of Friction (deg)
1.95	1.51	1.99	61	31
5.41	2.34	3.21	54	29
13.7	5.22	6.45	51	29

Table 2
Bulk Density Test Results

Major Principal Stress (kPa)	Bulk Density (kg/m^3)
0.0	590
1.1	860
2.3	890
6.7	1010
13.0	1110
25.5	1200
38.0	1280
50.5	1320

Table 3a
Wall Friction Test Results – 304 #2B Stainless Steel

Wall Material	Continuous Handling		After 24 hr Storage at Rest	
Normal Stress (kPa)	Shear Stress (kPa)	Wall Friction Angle (deg)	Shear Stress (kPa)	Wall Friction Angle (deg)
0.75	0.27	20	0.34	25
1.04	0.33	18	0.43	23
1.36	0.40	16	0.53	21
3.25	0.79	14	1.12	19
7.62	1.71	13	2.49	18
13.9	3.03	12	4.45	18
20.1	4.33	12	6.38	18

Table 3b
Wall Friction Test Results – Tivar 88

Wall Material	Continuous Handling		After 24 hr Storage at Rest	
Normal Stress (kPa)	Shear Stress (kPa)	Wall Friction Angle (deg)	Shear Stress (kPa)	Wall Friction Angle (deg)
0.75	0.34	25	0.24	18
1.04	0.43	23	0.30	16
1.36	0.53	21	0.36	15
3.25	1.12	19	0.76	13
7.62	2.49	18	1.68	12
13.9	4.45	18	3.00	12
20.1	6.38	18	4.30	12

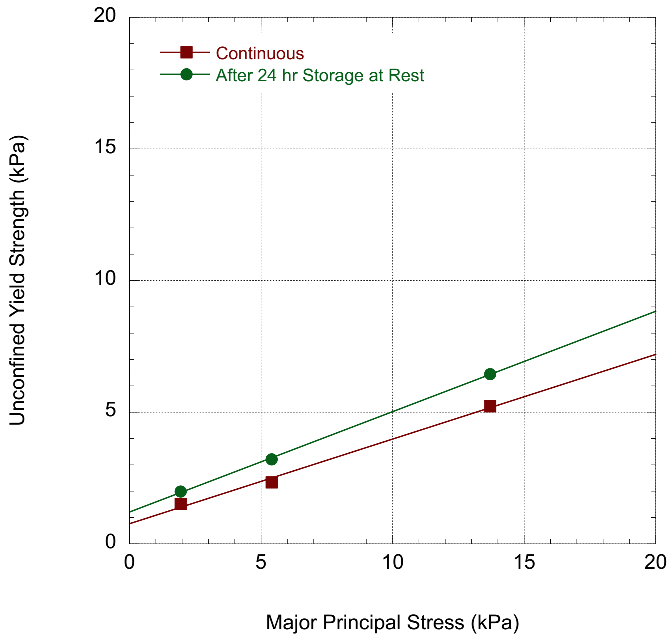

Figure 1. Cohesive strength.

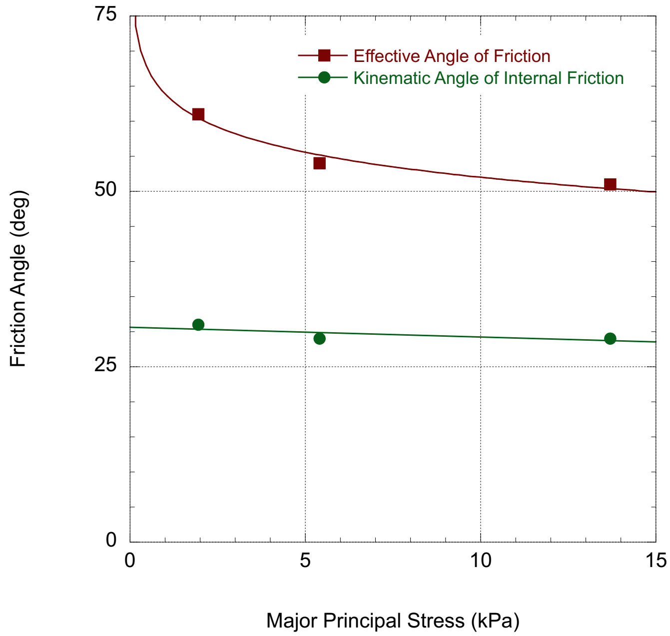

Figure 2. Internal friction.

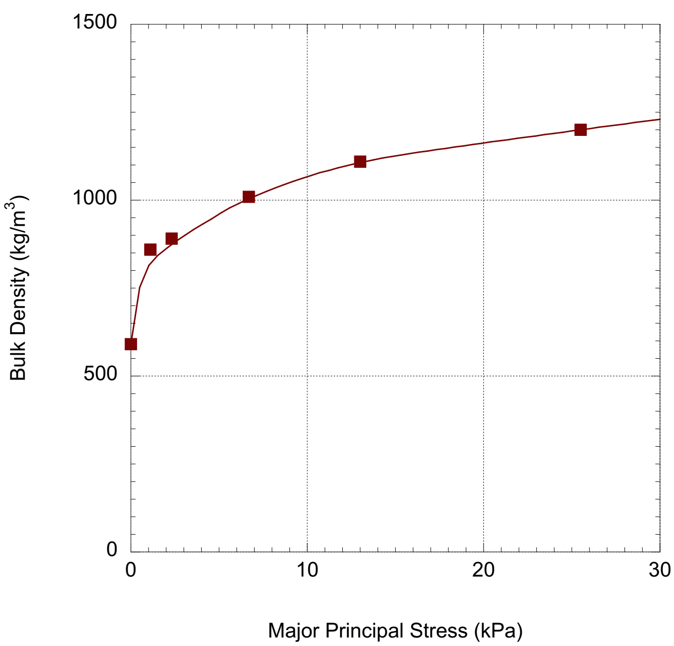

Figure 3. Bulk density.

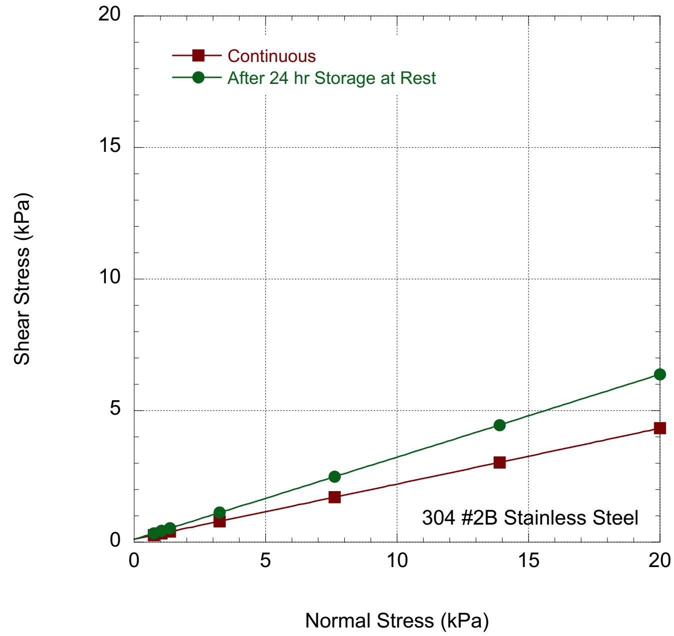

Figure 4a. Wall friction on 304 #2B stainless steel.

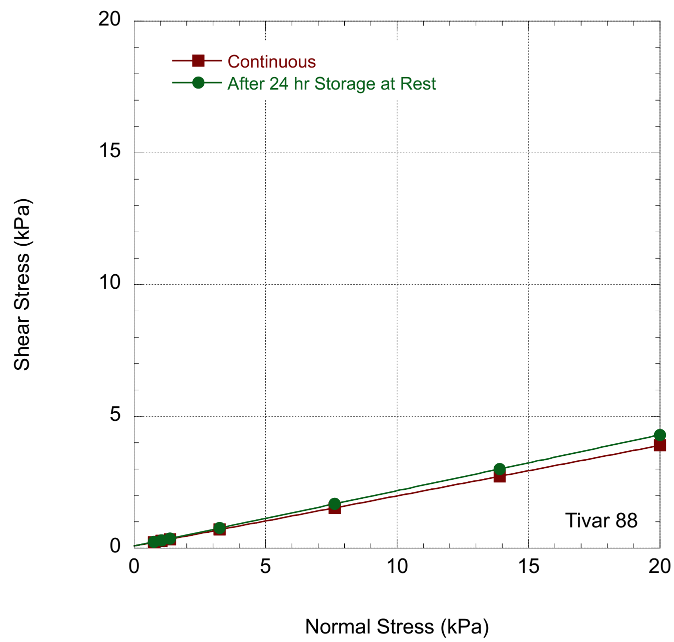

Figure 4b. Wall friction on Tivar 88.

Analysis

Using the test results, Andrew Jenike's analyses were performed to determine critical outlet dimensions to prevent obstructions to flow and recommended hopper angles for mass flow.

Minimum hopper outlet dimensions required to prevent arching are given in Table 4.

Table 4
Critical Arching Dimensions

Time (hr)	*BC* (mm)	*BP* (mm)	*BF* (mm)
0	340	160	210
24	580	265	370

BC = minimum outlet diameter to prevent arching in a conical mass flow hopper
BP = minimum width of a slotted outlet to prevent arching in a planar mass flow hopper
BF = minimum width of a slotted outlet to prevent arching in a planar funnel flow hopper

DF, the minimum outlet diameter to prevent formation of a stable rathole, depends on the maximum solids pressure (see Appendix). Critical rathole diameters are plotted against maximum solids stress in Figure 5.

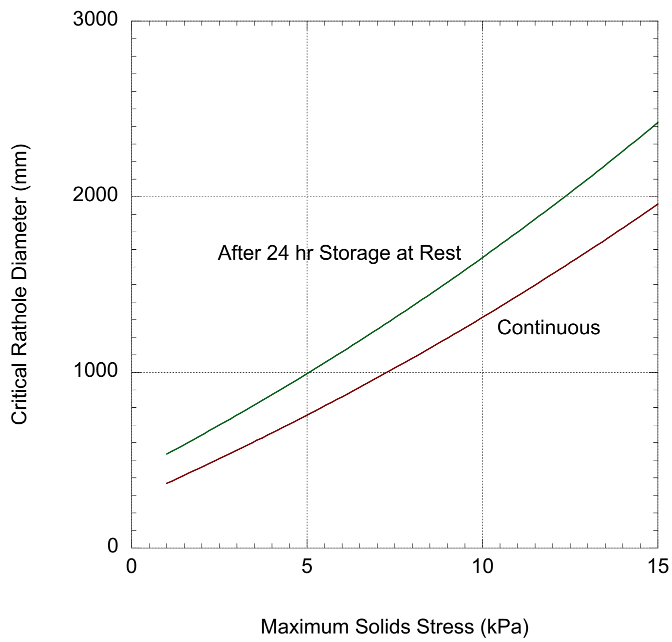

Figure 5. Critical rathole diameter.

The recommended mass flow hopper angle depends on hopper geometry, outlet size, and wall material. Recommended hopper angles for mass flow are given in Figure 6.

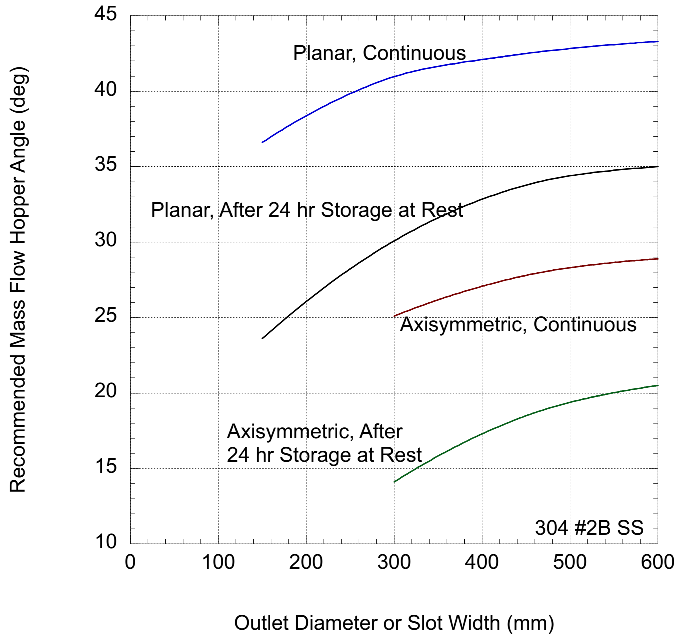

Figure 6a. Recommended mass flow hopper angles, walls fabricated or lined with 304 #2B stainless steel.

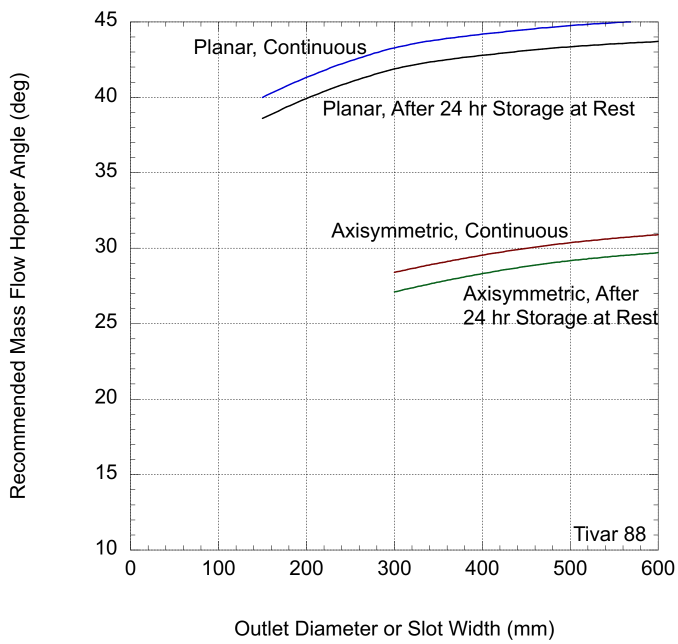

Figure 6b. Recommended mass flow hopper angles, walls lined with Tivar 88.

Appendix

All bins and hoppers must be properly designed to prevent obstructions to flow, *i.e.*, arches or stable ratholes (Figure A1).

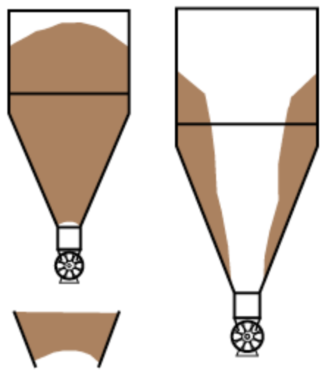

Figure A1. Obstructions to flow.

Mass flow, where all material inside the bin or hopper is in motion during discharge, is usually preferable. Mass flow occurs when the hopper walls are steep enough and low enough in friction to allow flow along them. Funnel flow is acceptable provided that the outlet of the vessel is large enough to collapse the ratholes that develop. An expanded flow bin, which is a mass flow hopper beneath a funnel flow hopper, is also acceptable provided that the outlet is large enough to prevent arching and its inlet to the lower hopper is large enough to prevent a stable rathole. Mass flow, funnel flow, and expanded flow bins are illustrated in Figure A2.

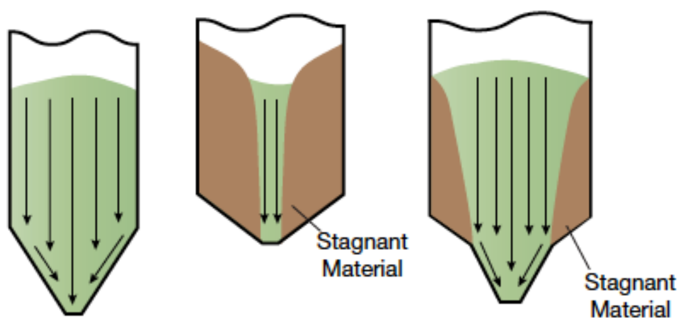

Figure A2. Solids flow patterns.

This report provides (1) minimum outlet dimensions of mass flow and funnel flow hoppers, (2) recommended mass flow hopper angles for axisymmetric (conical or pyramidal) bins and planar (wedge-shaped, transition, or chisel) hoppers, and (3) minimum funnel flow hopper outlet dimensions to prevent a stable rathole. Note that the critical outlet diameter depends on the maximum solids stress, which can be calculated from the Janssen equation:

$$\sigma_1 = \frac{\bar{\rho}_b g R_H}{k \tan \phi'} \left[1 - \exp\left(-\frac{k \tan \phi' z}{R_H} \right) \right]$$

where σ_1 is the major principal stress, g is acceleration due to gravity, $\bar{\rho}_b$ is the material's average bulk density, R_H is the hydraulic radius of the cylinder, k is the Janssen coefficient (typically assumed equal to 0.4), ϕ' is the wall friction angle, and z is the distance ($z = 0$ at the top level of the powder). In the cylinder (vertical-walled section), the wall friction angle is a function of the stress normal to the wall, which is equal to $k\sigma_1$. For small bins, an estimate of the maximum solids stress is $\sigma_1 = 2\rho_b g R_H$ where R_H is the hydraulic radius, *i.e.*, the cross-sectional area of the cylinder section divided by its perimeter.

Outlet dimensions greater than the minimum and hopper angles steeper than the recommended values can be specified. The planar mass flow hopper angle can be *ca.* 10 degrees shallower than the recommended angle.