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Sugar Mixing, Heat Generation Tests

Two tests were conducted to determine the rate of heat rise when mixing powders in a LabRAM and RAM5 mixers. One test used a LabRAM loaded with 0.1 kg granulated sugar and 0.1 kg powdered sugar, which was used to show the difference in heat generation of the same material composition and mass, but with different particle sizes. A second test was conducted using the RAM5, containing 3.78 kg of granulated sugar, which shows how the heat generation scales with larger batches holding the machine acceleration constant.

0.1 kg of Granulated Sugar was mixed on the LabRAM mixer in a standard 16 oz. polystyrene vessel for 14.5 minutes at 80 g of acceleration. The temperature increased from 20°C to 76°C. The plot of the temperature increase with respect to mix time is displayed below in Figure 1.

By placing a thermocouple in the vessel and assuming that heat into the vessel on initial heat up is minimized and all the heat is going into the heat capacity of the granular sugar, the relation of energy absorbed by the sugar as $E = m\ C_p\ \Delta T$ was used. Where m is the total mass of the sugar, C_p is the specific heat capacity of the sugar, and ΔT is the change in temperature. The initial power going into the sugar can be calculated by $P = E/t$. For this first order analysis the heat absorbed by the plastic vessel was neglected.

E is the energy over a given time, and t is the time between the two temperature measurements. The vessel arrangement is shown below in Figure 2 with air cooling, but for the first test air cooling was not used.

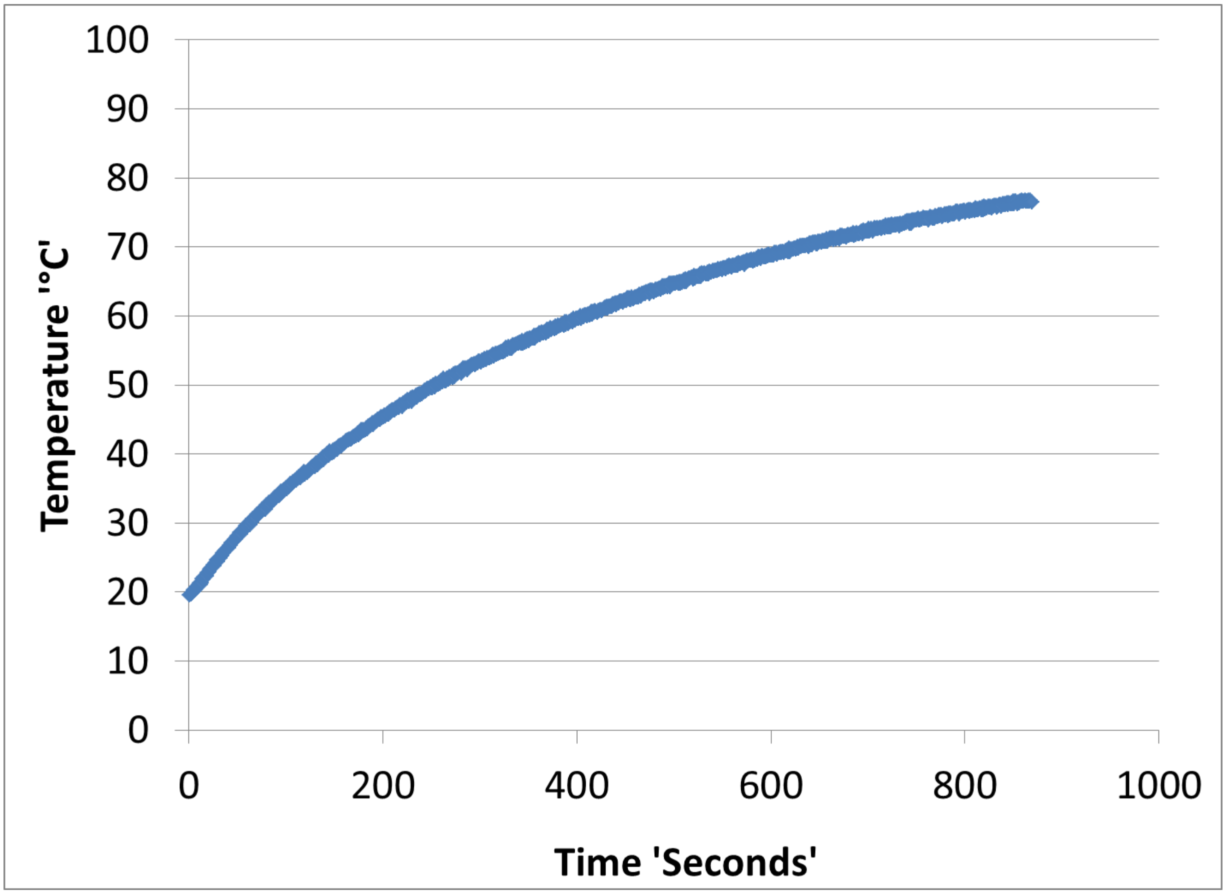

Figure 1. Temperature Increase vs Time mixing 100 grams of granulated sugar at 80 g of acceleration. No cooling air was blown across the outside of the vessel.

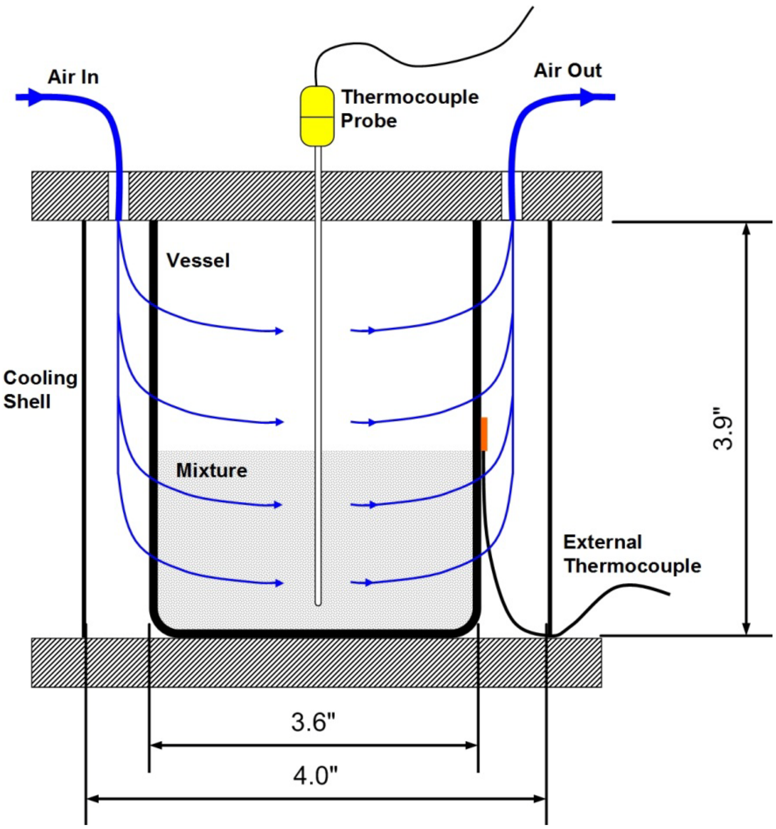

Figure 2. Vessel Test Schematic for LabRAM Mixer

By using 10 cfm air cooling around the vessel, which was accomplished by using a cooling shell surrounding the vessel, the internal temperature of the granulated sugar was lowered as shown in Figure 3.

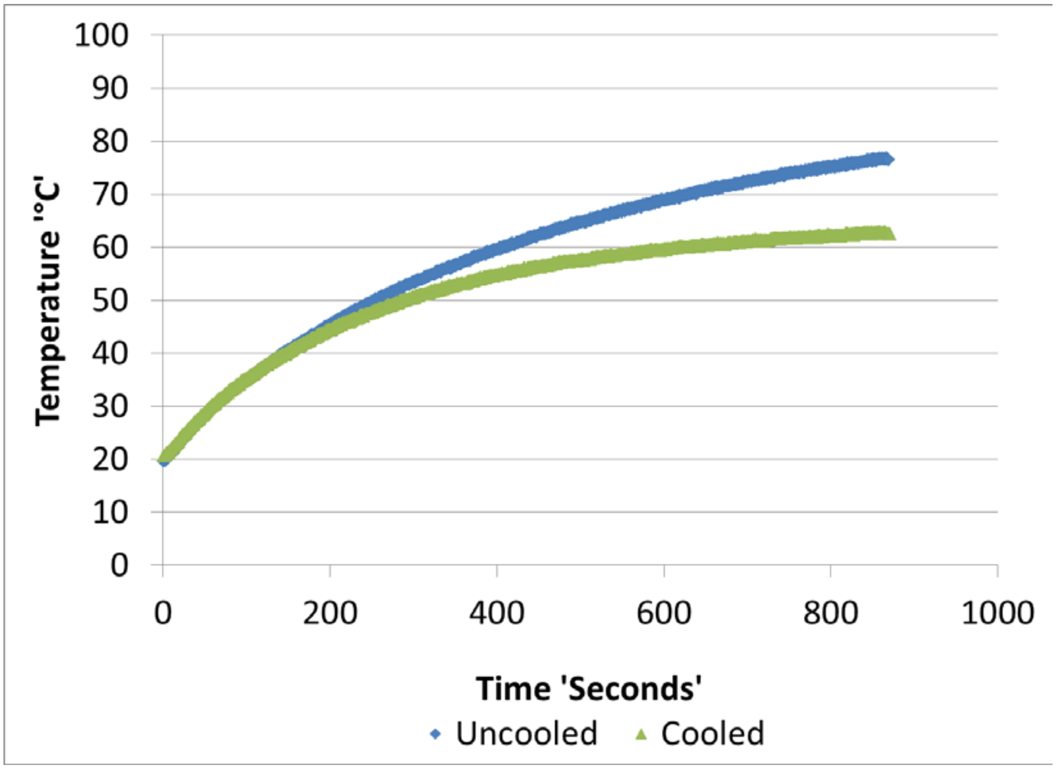

Figure 3. Temperature Increase vs Time mixing 100 grams of granulated sugar at 80 g of acceleration. Both cooled and uncooled conditions are provided.

An investigation of mixing powder sugar was performed. Mixing conditions at ambient and cooled with forced air were performed. Test conditions included 80 g of acceleration while mixing 100 grams of powder sugar. The temperature rise for the powder sugar tests for the cooled and un-cooled are displayed in Figure 4. The heat generation of the powdered sugar was much less than the granulated sugar when operating the mixer at the identical acceleration conditions of 80 g.

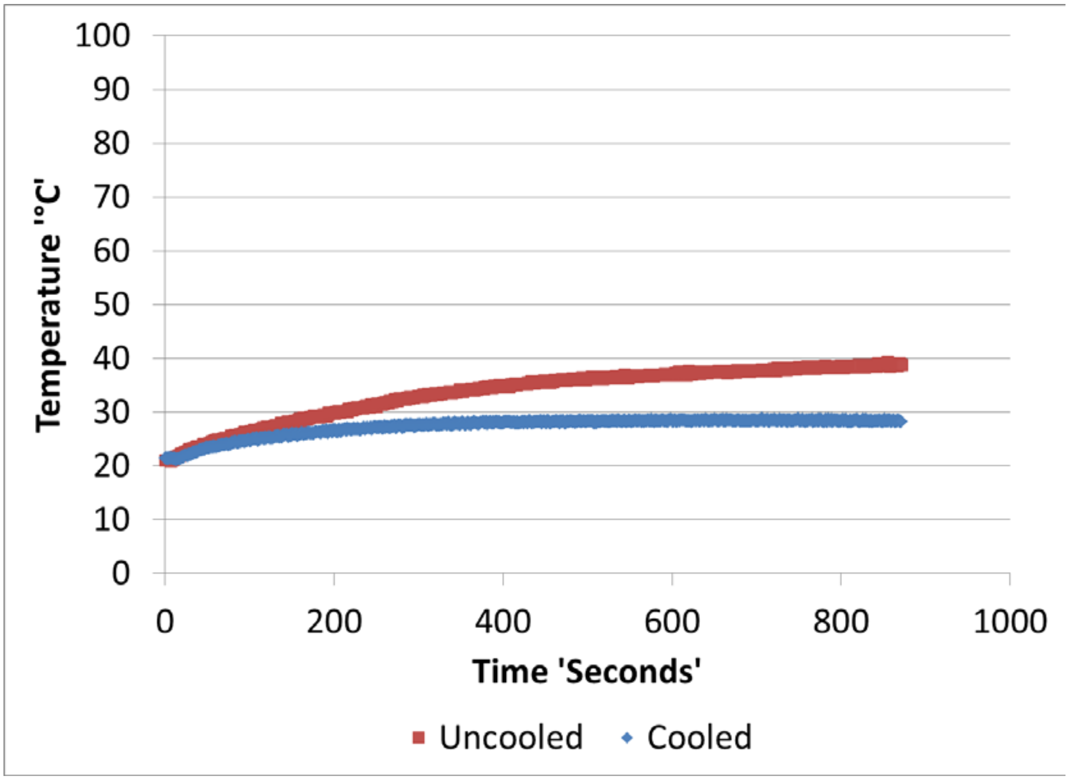

Figure 4. Temperature Increase vs Time mixing 100 grams of powdered sugar at 80 g of acceleration. Both cooled and uncooled conditions are provided.

A granulated sugar test of 3.78 kg was also run on the RAM5 at 80 g of acceleration. A comparison was then made of the heat generation rate per kilogram of the granulated sugar in the two machines while operating at the same acceleration.

In order to quantify how much energy is being generated, stored, and lost to the surroundings an energy balance was performed on the mixing system. The energy balance indicates the amount of power input into the mixture, minus the heat lost due to convection, is equivalent to the time rate of change of the thermal energy contained in the mixture. The energy balance is represented by the following equation:

$$mCp\frac{dT}{dt} = P - hA(T - T_{amb}) \qquad (1)$$

Where: m = mass of mixture; A = surface area

Cp = specific heat of the mixture; P = power input

T= temperature of the mixture; t = time

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h = convective coefficient

The left hand side of the Equation (1) represents the heat charging rate while the term on the right side of Equation (1) represents the heat loss by convection. The P term is composed of the power consumed by the machine and the power consumed by the mixture. On the left side of Equation (1) the mass is known (0.10 kg and 3.78 kg) and the specific heat of the mixture was estimated as 1244 J/kg*K. The heating rate was directly measured for a series of mixing tests using the thermocouple shown in Figure 2. When the material is beginning to heat up, most of the energy is going into heating the internal material and the vessel. Little energy is lost to the outside through convection because the temperature differential is very low. Figure 5 plots the energy being stored as heat in the sugar by the $mCp\frac{dT}{dt}$ term. The heat generation rate of the two scales of mixing on the LabRAM and RAM5 both started between 220 and 250 'Watts/kg, as pointed out in Figure 5. Because the two systems measured heat rate started out close to each other the amount of energy going into the mix on a per kilogram bases are close. A more rigerous analysis, which also includes the energy stored in the vessel, would need to be performed before the scaling of heat generation per kilogram could be confirmed. The heat dissipation is less at the higher temperatures for the RAM5 because the RAM5 vessel has a surface area to volume ratio less than the LabRAM vessel used. Thus, more energy is being stored as heat in the RAM5 mix test than for the LabRAM tests, which is displayed in Figure 5. The tests were ran in a off the shelf 5 gallon steel bucket. The test configuration of the RAM5 vessel is displayed in Figure 6.

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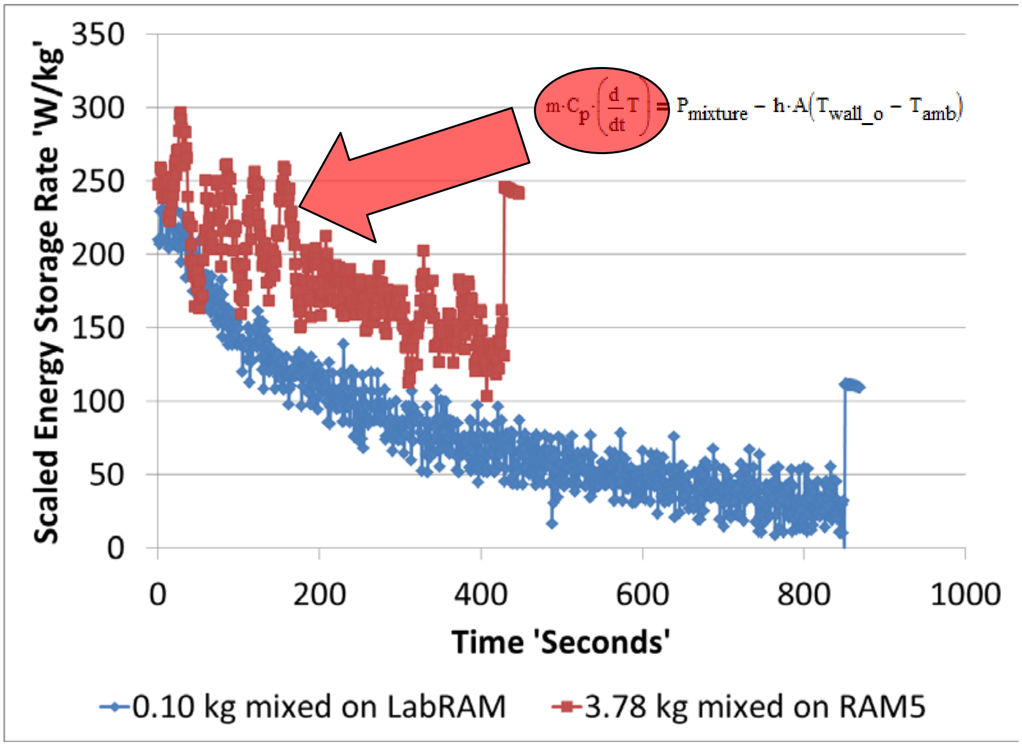

Figure 5. Energy Storage Rate of Heat in the Sugar vs Time for both Granulated sugar tests on the LabRAM and RAM5 Mixers. The energy storage rate plotted is scaled per kilogram to show that the energy per kilogram are equivalent for the two systems.

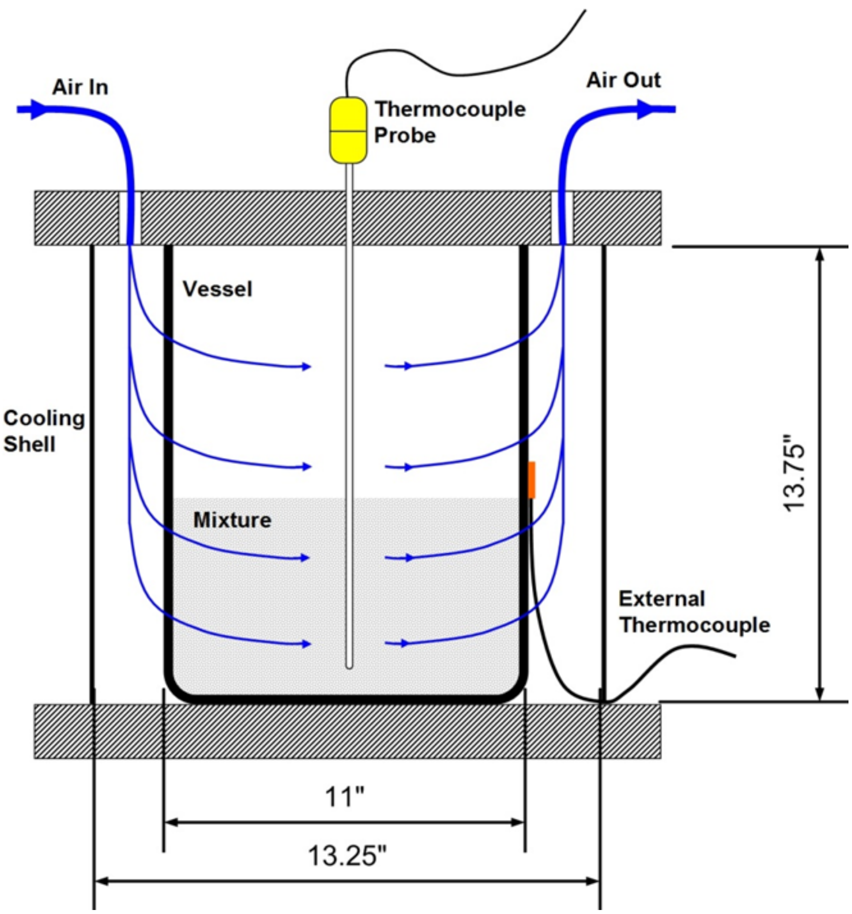

Figure 6. Vessel Test Schematic for RAM5 Mixer

From the first experiment, by mixing: 1) The equivalent material composition, 2) equivalent mass, 3) mixing conditions, and 4) varying the particle size; the amount of heat generation (amount of mixing) was not equivalent. Therefore, by mixing with the same material, mixing results may vary by changing the material particle size. In addition, by using air to cool the outer wall of the vessel the temperature of the material being mixed can be controlled.

The second experiment (scaling) indicated that the energy input to the materials being mixed in the RAM is the same per kilogram when the same mixing acceleration, vessel loading percentage, material composition and material particle size are used in different sized vessels. Therefore, when scaling the technology, larger batch heat generation rates can be scaled directly from bench scale mixes. These heat generation rates can then be used to size the cooling requirements for the scaled batches.

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