Project Title: "WET SOLIDS FLOW ENHANCEMENT"

Semi-Annual Report
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SUMMARY OF TECHNICAL PROGRESS:

ABSTRACT:

The objective was to visualize the flow of granular material in the silo using Nuclear Magnetic Resonance. This was done by introducing tracers. Mustard seeds and poppy seeds were used as trace particles. The region sampled was a cylinder 25 mm in diameter and 40 mm in length. Eight slices containing 128*128 to 256*256 pixels were generated for each image.

INTRODUCTION:

Nuclear Magnetic Resonance Imaging can be used to study the flow of granular material noninvasively inside the container. In NMR imaging, a detectable signal is produced by spin-spin (T_2) relaxation. But T_2 relaxation time is usually very short (less than 1msec) in the solid state. So the signal from the solid state particles decays too rapidly to produce a detectable signal. The easiest nuclei to image by NMR are protons in the liquid state because of their strong signal as well as their abundance in nature. We can avoid the solid state NMR problem by using solid particles containing protons in the liquid state. So we study flow of solids by liquid state NMR.

Mustard seeds and poppy seeds were used as trace particles. Proton spin density images were obtained using a Bruker (Amx 360) Nuclear Resonance Imager. Multi-slice multi-echo pulse sequence was used for all imaging experiments. The imaging probe operated at 360.13 MHz for proton. The gradient strengths were: read gradient Gx=4.69 Gauss/cm, phase encoding gradient Gy=4.69 gauss/cm, and slice selection gradient Gz=21.52 Gauss/cm for a 1.0 mm slice thickness. Typically, 8 slices were acquired with a repetition time (Tr) of 2000 ms and an echo time (Te) of 20 ms. Spyglass Slicer software purchased from Fortner Research (Sterling, Virginia) was used to analyze images.

RESULTS:

Figure 1 shows an NMR image of mustard seeds with glass beads. This is a transverse slice. Glass beads, being in solid state, do not give any detectable signal.

Figure 2 shows a schematic diagram of the cylindrical silo used for imaging experiments. The silo was made of polyacrylate and was provided with a slide valve to control the solid discharge.

Stop and flow experiments were done using glass beads. Figure 3 shows the flow patterns in glass beads as the material is discharged from the silo. Funnel flow type of flow patterns were observed. The average diameter of the glass beads was 2.5mm. Nine layers of poppy seeds, separated by approximately 1 cm, were used as markers. The poppy seeds layers have been numbered to keep track of their successive positions. The total bed height was 11 cm. The material was discharged from the silo by using the sliding valve. The imaging window was 4 cm long and 2.5 cm in diameter(figure 2). Figure 3a shows the layers of poppy seeds in glass beads before any discharge of the material. Figures 3b-3f show the successive position of the poppy seeds layers after approximately 0.80 gm of the glass beads were discharged between images. Figures 3g-3j show the successive position of the poppy seeds layers after the discharge of approximately 2.2 gm of the glass beads between images. In first 6 discharges, there was no wall effect on the flow patterns (Figures 3b-3g). With further discharge, the boundaries of funnel flow reached the wall (Figures 3h-3j).

FUTURE WORK:

Mechanical properties of the wet granular materials will be studied next. The surface tension and the contact angle of the wetting liquid are two main factors which affect the yield loci of the wet granular materials. Therefore, liquids of different surface tensions needs to be used. The contact angle will be controlled by modifying the surface of the granular materials. Scale up to a larger scale imager, where larger scale solids flow can be observed, is also planned.

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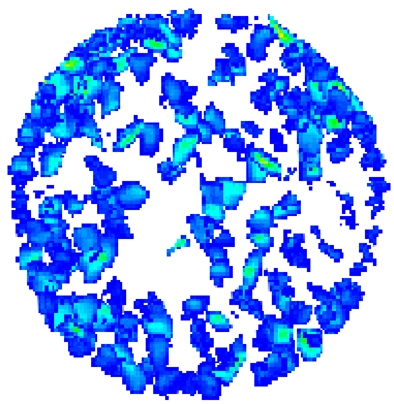


Figure 1: NMR image of mustard seeds with glass beads

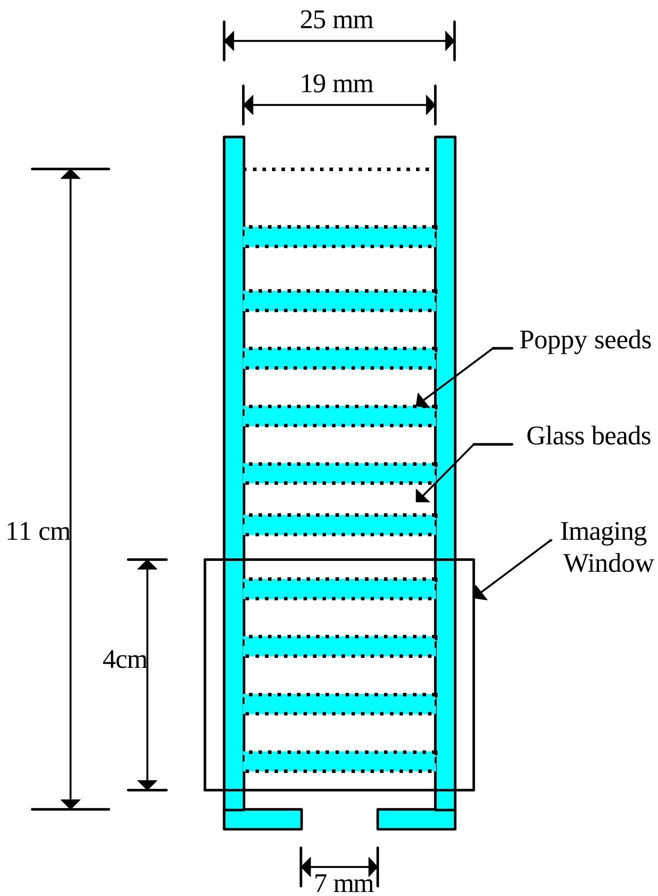
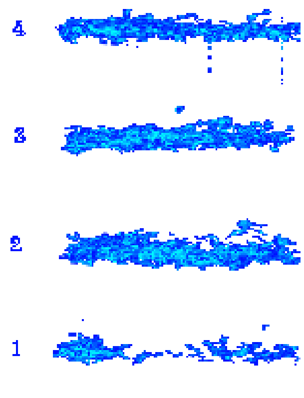


Figure 2: Schematic diagram of the silo



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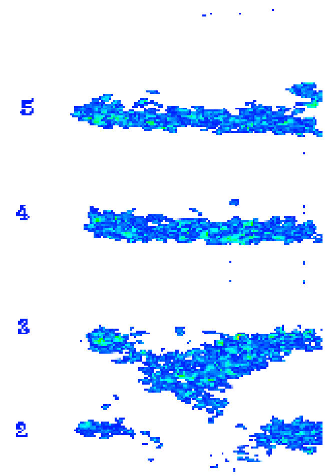

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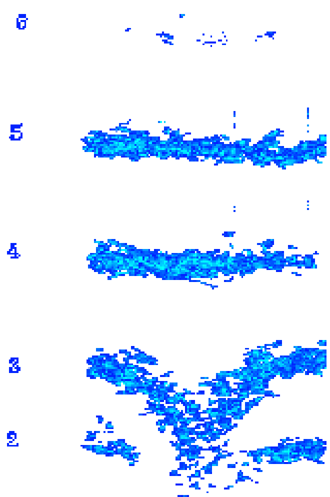

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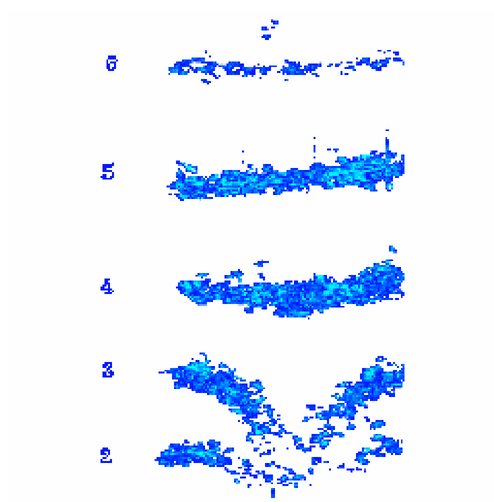

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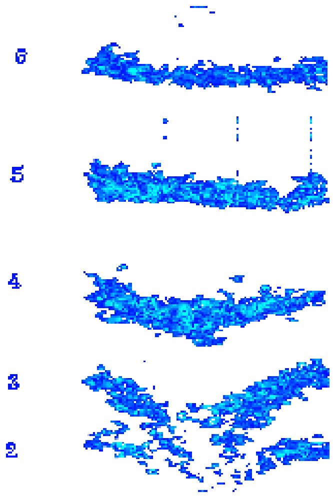

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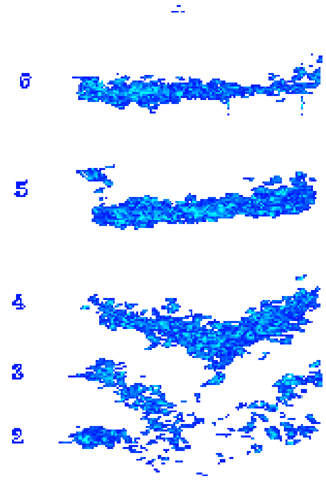

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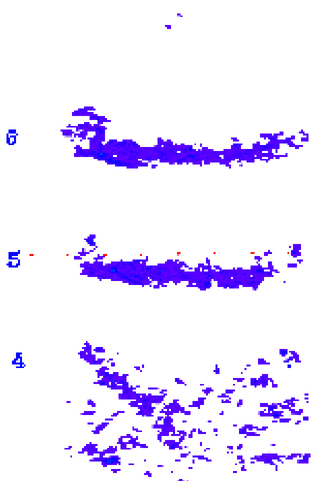

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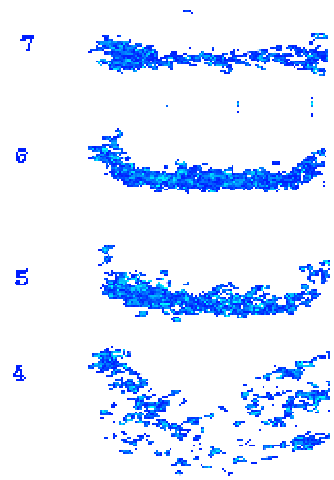
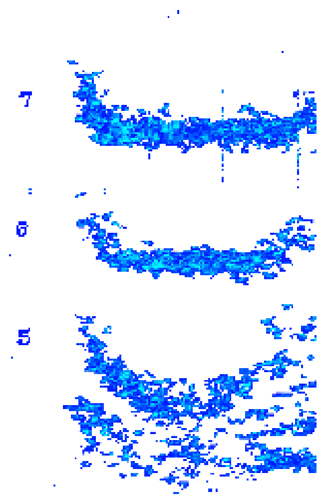


3(h)



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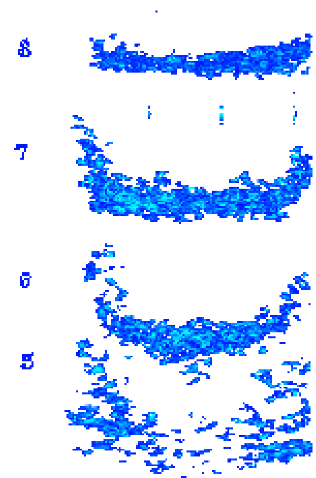

3(j)

Figure 3: NMR image of the flow patterns in the silo