**Calibration Models for Measuring Moisture
in Unsaturated Formations by Neutron Logging**

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Summary

Calibration models containing known amounts of hydrogen have been constructed to simulate unsaturated earth formations for calibrating neutron well logging tools. The models are made of dry mixtures of hydrated alumina $\{\text{Al}(\text{OH})_3\}$ with either silica sand (SiO_2) or aluminum oxide (Al_2O_3). Hydrogen in the hydrated alumina replaces the hydrogen in water for neutron scattering, making it possible to simulate partially saturated formations. The equivalent water contents for the models are 5%, 12%, 20%, and 40% by volume in seven tanks that have a diameter of 1.5 m and a height of 1.8 m. Steel casings of inside diameter 15.4 cm (for three models) and diameter 20.3 cm (for four models) allow logging tool access to simulate logging through cased boreholes.

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1.0 Introduction

Moisture (i.e., water) within the unsaturated formation is the carrier medium for most contaminants. Its quantification is of fundamental importance for site characterization because moisture data are primary inputs for contaminant transport models. Monitoring moisture concentrations within the unsaturated formation is used to 1) detect leaks or spills from engineered structures and 2) identify and track contaminant migration fronts, especially those that do not contain readily identifiable contaminants (e.g., gamma-ray emitters).

Many methods used within the agricultural and environmental industries quantify soil moisture (Klute 1986). Two of the most commonly used, especially at environmental sites, are gravimetric analysis and moisture gauges. In gravimetric analysis a sample is weighed (w_o), dried in an oven, and reweighed (w_d). The gravimetric water content (gw) can be calculated by

$$gw = [(w_o - w_d) / w_d].$$

Gravimetric water measurement provide very precise results; however, this *ex situ* measurement requires that a sample be extracted limiting its utility for monitoring. The sample is typically small and may not be representative of heterogeneous formations. Furthermore, the analysis can not compensate for changes that may occur to the sample as a result of extraction and transport to a lab, and grain density and porosity must be estimated in order to convert the results to a volume basis.

In situ quantification of moisture addresses many of the limitations of gravimetric analysis listed above. The moisture gauge is a commonly used *in situ* analysis methods. Moisture gauges are introduced into the formation through a borehole, and they measure (Goodspeed 1981) the thermalization of neutrons by water. The probes typically have a small, high-energy neutron source (50 mCi Am-Be) with a single, closely-spaced detector. As the high-energy neutrons collide with the formation, they lose energy through collisions with nuclei and are eventually slowed to thermal energies (~0.02 eV). Once at these energies the neutrons can be detected by the gauge. The hydrogen nucleus is particularly efficient in slowing down neutrons, so system response is primarily a function of the hydrogen concentration. Because of the short source-detector spacing, the thermal neutron count rate increases as moisture content increases (Hearst and Carlson 1994).

As with all technologies, there are limitations to the moisture gauge. One limitation is the small source and its effect on measurement precision. The standard deviation of a nuclear measurement is proportional to the square root of the number of counts (Ellis 1987). Thus, a moisture gauge must take stationary measurements in order to get acceptable precision. The detector is sensitive to thermal neutrons primarily because they are more abundant than the slightly higher energy epithermal neutrons, thus promoting better counting statistics. Thermal neutrons, however, are prone to capture by specific nuclei (e.g., boron, cadmium); thus, the presence of small quantities of these nuclei will affect the moisture measurement.

The petroleum industry use neutron-neutron logging systems for quantification of formation hydrogen, typically in water-filled oil and gas wells and liquid-saturated formations (Tittle 1961; Tittman et al. 1966; Allen et al 1967; Ellis 1990). These systems also rely on neutron thermalization for moisture detection; however, the neutron-neutron logging systems (Figure 1) use much larger sources (16 to 20 Ci AmBe) and multiple detectors to promote faster logging speeds and compensation for borehole effects, respectively. In addition, many of these systems use neutron detectors that are not sensitive to thermal neutrons, they only detect epithermal neutrons which are not effected by thermal absorbers.

Both the moisture gauge and neutron-neutron logging system count neutrons that return to the system after interactions with the formation. Calibration is necessary to convert these counts to moisture quantities. Calibration models containing known amounts of moisture provide a means to

calibrate these tools, and models for neutron-neutron systems have been built to simulate formations that are saturated with water. The American Petroleum Institute's models in Houston, Texas (Belknap et al. 1959) and the EUROPA models in Aberdeen, Scotland (Butler et al. 1986) are examples of such models, which are made from blocks of quarried rock.

Logging is typically provided as a service by independent vendors who develop and deploy calibrated systems. Qualified neutron-neutron logging has not been routinely performed at the Hanford Site, in part because the logging vendors have not calibrated their systems for the Hanford borehole environment. As stated above, most oil and gas wells are water-filled and the surrounding formation is saturated. The Hanford formation, in contrast, is subsaturated and the borehole is air-filled. The difference in hydrogen content leads to very different neutron transport properties. Also, the typical oil or gas well is logged prior to insertion of casing; the Hanford borehole must be cased as it is advanced because the Hanford formation is unconsolidated. Consequently, logging tools that normally operate in uncased boreholes must be recalibrated to account for the effects of the steel casing on the measurement.

Models also exist that are suitable for environmental logging applications (Stromswold 1995). Hearst (1994) has constructed models at the U. S. Department of Energy's Nevada Test Site to calibrate neutron tools for use in large (2.4-m and 30-cm diameter), uncased boreholes above the water table. The models reported here for the U. S. Department of Energy's Hanford Site are somewhat similar to the ones in Nevada, except that the Hanford models have steel casings and none of the models contain free water. Thus they are suitable for calibrating logging tools typically run at Hanford through steel casing above the water table.

The models were built as part of Cooperative Research and Development Agreements (CRADAs) by the U.S. Department of Energy, Pacific Northwest Laboratory, Westinghouse Hanford Company, and two commercial vendors of borehole geophysical measurements, Halliburton Energy Services and Schlumberger Well Services. The CRADAs covered adaptation of neutron moisture, spectral gamma ray, and density well logging systems for environmental applications at arid locations such as Hanford. A separate report (Engelman et al. 1995) describes the construction of calibration models for use with logging tools that measure formation density.

Figure 1. Neutron Logging Tools. On left, conventional design with dual detectors and steady-state neutron source; on right, different design with multiple detectors and pulsed neutron generator.

2.0 Model Specifications

A large number of gravimetric moisture data are available for the Hanford formation. Over 3600 analyses from the unsaturated Hanford formation were downloaded from the Hanford Environmental Information System (HEIS) database. They were converted from weigh % to volume percent by assuming that the porosity is 40% and the grain density of 2.8 g/cm³. The results are displayed in Figure 2. The figure shows that the amount of moisture in the vadose zone at Hanford is typically in the 4 to 40% (by volume) range, with the most frequent value being about 5%. For such low moisture contents, the pore spaces between the rock grains are only partially saturated with water.

A limited amount of bulk density measurements are available for the unsaturated Hanford formation, approximately 550. All are ex situ measurements made on core data and have been compiled in Figure 3. The mean value is 1.81 g/cm³, the median is 1.79 g/cm³, and the mode is 1.70 g/cm³. Published sources for these data include Rhoads et al. (1992), Rohay et al. (1993), Swanson (1992), and Wright et al. (1994). They account for approximately 200 measurements; the remainder were downloaded from a Westinghouse Hanford Company database.

The moisture calibration models were designed to cover the Hanford moisture range and to have a bulk density representative of actual formations. The models are contained in seven cylindrical tanks, each with a steel casing along its axis for logging tool insertion. Table 1 gives the equivalent moisture content (expressed as volume fraction water), density, and casing diameter for each model. The appendices give additional, detailed information about the models, including weights of materials used in each model. Six of the models contain uniform mixtures to achieve a specific moisture content, and one model contains a 102-cm-thick zone of 40% moisture between two 5%-moisture zones. Specifying the moisture content as "volume fraction water" conforms to traditional neutron logging methodology, which uses volume fraction rather than weight fraction. In the case of dry materials containing hydrogen, such as the materials in the Hanford calibration models, volume fraction water is the equivalent volume fraction that water would occupy while having the same hydrogen content.

Table 1. Neutron Moisture Models Specifications

Model Number	Volume Fraction Water	Density (g/cm ³)	Casing Inside Diameter	
			(cm)	(in.)
F	0.050	1.76	15.4	6
E	0.117	1.74	15.4	6
G	0.198	1.70	15.4	6
A	0.050	1.76	20.3	8
C	0.119	1.76	20.3	8
B	0.197	1.70	20.3	8
D (thin zone)	0.409	1.32	20.3	8

Monte Carlo modeling of a neutron logging tool in the tanks guided the choice of tank diameters. The tanks containing the models are sufficiently large so that even at low moisture content, the neutron moisture measurements will not be perturbed by edge effects. In addition, the large size of the tanks provides additional containment of the neutrons, which is important for safety reasons because the tanks are installed above ground. The tanks are made of stainless steel, and they are 1.8-m tall and 1.5 m in diameter. Steel casings of two different diameters (15.4-cm and 20.3-cm inside diameters) are present in the tanks. Casings of these diameters are typically used at Hanford to prevent unconsolidated formations from collapsing into the hole. Each tank is permanently mounted

and welded in its own steel pallet for ease of moving. Figure 4 shows the design of the tanks, and Table 2 gives a summary of their specifications. Lids with gaskets bolted atop the tanks reduce the chance of moisture change over time caused by changes in water vapor. The low humidity at Hanford during construction of the tanks minimized the amount of entrained water vapor.

Figure 2. Moisture Content in the Unsaturated Hanford formation

Figure 3. Bulk Density of Unsaturated Hanford formation

Figure 4. Calibration Model Design

Table 2. Tank Specifications

Height (inside)	1.9 m (75 in.)
Diameter (inside)	1.5 m (59.5 in.)
Wall thickness	0.64 cm (0.25 in.)
Material	stainless steel, 300 series, ASTM 240
Well casings	carbon steel, ASTM A53, type S, grade B {three casings with 15.4 cm (6.06 in.) inside diameter and wall thickness 0.71 cm (0.28 in.); four with 20.3 cm (7.98 in.) inside dia. and wall thickness 0.82 cm (0.322 in.)}
Pallet	stainless steel, 300 series, ASTM 240, 1.8 m x 1.8 m x 0.2 m (6 ft x 6 ft x 8 in.)
Manufacturer	Bamco Technologies, Lynwood, Washington

The contents of the models are two-component, dry mixtures of hydrated alumina $\{\text{Al}(\text{OH})_3$ or, equivalently, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}\}$ and either SiO_2 or Al_2O_3 . Hydrated alumina provides the hydrogen to simulate partially saturated formations without the need for using water, which would be difficult to distribute uniformly in the models without completely saturating the pore spaces. The water molecules in $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ are firmly bound, requiring temperatures of about 300° C to remove them. The Al_2O_3 is used only in the 40%-moisture model to increase its bulk density without vibrating it for compaction. Table 3 gives the specifications of the materials used in the models.

Table 3. Materials Used for Models' Contents

Hydrated alumina	formula: $\text{Al}(\text{OH})_3$ or $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ grain density: 2.42 g/cm ³ (measured by PNL and Alcoa) particle size: 0.076-0.28 mm (200-50 sieve- International std.) manufacturer/identification: Alcoa C-30 bound water: 34.6 to 35.0 wt% (Alcoa) (a) 35.2± 0.9 wt% (PNL) free water: 0.01 to 0.05 wt% (Alcoa) (b)
Silica sand	formula: SiO_2 grain density: 2.64 g/cm ³ (measured by PNL and Unimin) particle size: 0.20-0.84 mm (70-20 sieve) manufacturer/identification: Unimin Corporation - Ottawa sand
Tabular aluminum	formula: Al_2O_3 grain density: 3.76 g/cm ³ (measured by PNL and Alcoa) particle size: 0.076-0.28 mm (200-50 sieve) manufacturer/identification: Alcoa T-64
Suppliers	Schoofs, Inc., Moraga, CA 94556 ($\text{Al}(\text{OH})_3$ and Al_2O_3) Unimin Corporation, New Canaan, CT 06840 (SiO_2)

(a) determined by weight loss on heating to 1100°C

(b) determined by weight loss on heating to 110°C

3.0 Hydrogen Content for Model Components

3.1 Hydrogen Index of Hydrated Alumina

Neutron logging tools effectively measure the amount of hydrogen present in the volume of a formation interrogated by a logging tool. For a dry mixture, such as in the calibration models, the hydrogen is determined by the bound hydrogen of the individual components. For the materials in the models, only hydrated alumina $\{\text{Al}(\text{OH})_3\}$ contains hydrogen.

The hydrogen index (HI) is the ratio of the number of atoms of hydrogen in a given volume of material to the number of hydrogen atoms in the same volume of pure water. The HI of solid hydrated alumina, based on a molecular weight of 78 and a grain density of 2.42 g/cm³, is calculated as follows:

$$\begin{aligned} \text{H atoms in 1 cm}^3 \text{ of solid Al(OH)}_3 &= [2.42 \text{ g/cm}^3 / 78 \text{ g/mole}] [N_0 \text{ molecules/mole}] [3 \text{ H-atoms/molecule}] \\ &= 0.0931 N_0 \end{aligned}$$

where

N_0 = Avogadro's number

Similarly, for H_2O

$$\begin{aligned} \text{H atoms in 1 cm}^3 \text{ of water} &= [1.00 \text{ g/cm}^3 / 18 \text{ g/mole}] [N_0 \text{ molecules/mole}] [2 \text{ H-atoms/molecule}] \\ &= 0.111 N_0 \end{aligned}$$

The HI of $\text{Al}(\text{OH})_3$ is

$$\begin{aligned} \text{HI (Al(OH)}_3) &= [\text{H in Al(OH)}_3 \text{ (unit volume)}] / [\text{H in water (unit volume)}] \\ &= [0.0931 N_0] / [0.111 N_0] \\ &= 0.838 \end{aligned}$$

Thus, $\text{Al}(\text{OH})_3$ contains 83.8% of the hydrogen as the same volume of water.

3.2 Two-Component Mixtures

For a two-component mixture containing $\text{Al}(\text{OH})_3$ and a non-hydrogen-containing component, such as SiO_2 , the HI of the mixture is

$$\text{HI}_m = [V_A/V_t] \text{HI}_A$$

$$\text{HI}_m = [1/\rho_{g,A}][f_A \rho_{g,m} (1-\phi) \text{HI}_A]$$

$$\text{HI}_m = [1/\rho_{g,A}][f_A \rho_{b,m} \text{HI}_A] \quad (1)$$

where

V_A = volume occupied by solid hydrated alumina
 V_t = total volume occupied by mixture (includes air space between grains)

HI_A	= hydrogen index of hydrated alumina ($Al(OH)_3$): 0.838
$\rho_{g,A}$	= grain density of hydrated alumina ($Al(OH)_3$): 2.42 g/cm ³
f_A	= mass fraction of hydrated alumina (m_A/m_m)
$\rho_{g,m}$	= grain density of mixture
ϕ	= porosity (volume fraction between grains, filled with air)
$\rho_{b,m}$	= bulk density of mixture (includes air space between grains)

The HI of the mixture depends on how tightly the two components mix to reduce the porosity between the grains. Achieving a specific HI and bulk density requires skill and experience in selecting relative proportions of the components, mixing them together, and vibrating the mixture to achieve a desired bulk density and compaction that will inhibit subsequent settling. The bulk density of a mixture depends on the grain densities and masses of the solid components and on the porosity:

$$V_t = \phi V_t + V_A + V_2$$

$$V_t = \phi V_t + m_A/\rho_{g,A} + m_2/\rho_{g,2}$$

$$1 = \phi + (m_A/\rho_{g,A} + m_2/\rho_{g,2})/V_t$$

$$1 = \phi + (m_A/\rho_{g,A} + m_2/\rho_{g,2})/(m_t/\rho_{b,m})$$

$$1 = \phi + (m_A/m_t \rho_{g,A} + m_2/m_t \rho_{g,2})\rho_{b,m}$$

$$1 = \phi + (f_A/\rho_{g,A} + f_2/\rho_{g,2})\rho_{b,m}$$

$$\rho_{b,m} = (1-\phi)[1/(f_A/\rho_{g,A} + f_2/\rho_{g,2})] \quad (2)$$

where

V_2 = volume of second solid component (for example, SiO_2)

m_A = mass of hydrated alumina

m_2 = mass of second solid component

f_2 = mass fraction of second component ($f_2 = 1 - f_{HA}$)

$\rho_{g,2}$ = grain density of second component (for example, 2.64 g/cm³ for SiO_2)

The mass fraction of hydrated alumina needed to achieve a specific HI for the mixture at an assumed porosity is obtained by substituting equation 2 into equation 1:

$$HI_m = [1/\rho_{g,A}] f_A (1-\phi)[1/(f_A/\rho_{g,A} + f_2/\rho_{g,2})] HI_A$$

Substituting $f_2 = 1 - f_A$ and rearranging terms gives

$$f_A = 1/[(1-\phi)\rho_{g,2} HI_A/(HI_m \rho_{g,A}) - \rho_{g,2}/\rho_{g,A} + 1]$$

4.0 Construction Techniques

Materials used to fill the tanks were weighed and then blended together in a small, paddle cement mixer with a volume of 0.2 m^3 (0.25 yd^3). Experience showed that the components mixed well when their total volume was no greater than one third of the capacity of the mixer. Typical mixing times were about 15 minutes. The white color of the hydrated alumina aided judgement of when the materials were sufficiently mixed with the darker sand. Figure 5 shows the filling of one of the models with material from the mixer. After several loads from the mixer were poured into the tank, the material was leveled and then vibrated for compaction. To fill a tank, 10 to 22 such "lifts" were placed into the tank with vibration taking place between each lift. The appendices give detailed information about the mixture components used in the lifts. Vibration reduced the void volume between the grains from an initial value of about 40% porosity before vibration to about 33% porosity after vibration. No vibration was used for the 40%-moisture model because vibration might have disturbed the interfaces between the central 40%-moisture zone and its adjacent 5%-moisture zones.

Figure 5. Process of Filling Model. Materials blended in mixer were transferred to model in "lifts" that were subsequently vibrated for compaction.

Vibration to achieve a bulk density similar to that encountered in formations at Hanford was an important part of the construction process. Vibration also helped to ensure that the material would not settle over time, thus changing the hydrogen index. Initial vibration tests with a scaled-down version of the models provided experience with vibration methods, although further experimentation was required for the full-size tanks to achieve an optimum vibration technique. Initial tests with the

large tanks employed vibrators that were attached to the sides of the tanks and moved upward as the tanks were filled. This was the conventional method used by other researchers in making sand-pack calibration models. Experience showed, however, that vibrating the base of the tank only improved compaction with less segregation of the material during vibration. For this method, the tank rested on four air bags, one at each corner of the metal pallet holding a tank. Four pneumatic vibrators located above the isolation bags vibrated the tank. Very rugged brackets were required for mounting the vibrators to avoid cracking under the stress. Table 4 contains information about the vibrators. Varying the air pressure to the vibrators changed their frequency and force of vibration. The two vibrators located diagonally opposite each other were oriented so that their horizontal vibration modes canceled, leaving mainly vertical vibration when the vibrators were properly synchronized. The vibrators were carefully positioned such that the axis of rotation was parallel for each vibrator in a diagonal pair. An air distribution manifold provided the means for distributing and adjusting the air pressure to the individual vibrators. Various vibration methods and times were tried while constructing the models. Slowly increasing the air pressure to the vibrators until they were synchronized and then slowly stopping, with an average vibration time of about 30 sec per vibration period, gave the best results. This was repeated 10 to 20 times for each lift. In general, more vibration periods were used as the thickness of material to be vibrated increased. The appendices contain additional details about the vibration methods. Although vibration sensors were attached to the tanks during some of the model construction, the sound of the vibrators and visual observation of the compaction proved to be the best guide for synchronizing the vibrators and establishing optimum compaction.

Table 4. Vibrators for Compacting Model Mixtures

Manufacturer	Vibco, Wyoming, Rhode Island
Model	PC-3500/4051A12
Type	Rotary, air-driven; 3500 lbs at 60 psi

Experiments with an alternative compaction method used a "densifier." In this method the entire tank was filled initially without compaction. The filled tank was lifted 5 to 10 cm on inflatable air cushions and then dropped under gravity. Before the tank hit the floor (hopefully), it was rapidly stopped by reinflating the air cushions. The acceleration produced compaction of the material in the tank. This method produced the desired compaction, but it required significant operator skill to prevent damage to the tanks. As a result, the densifier was not used in constructing the actual models.

The moisture and density values given in Table 1 for the models are based on the weights of the materials and the measured dimensions of the models. Measurements of the circumference of the tanks confirmed that the tanks did not expand as material was added to them. The height of model mixtures was measured at 15 locations over the surface of the sand after vibrating each lift. As indicated in the tables in the Appendices, 3 of the 15 points were around the central casing, 8 of the points were around the outer edge of the tank, and 4 of the points were in the middle region between the pipe and the outer tank edge. The grain densities for the constituent materials were measured in the laboratory. The hydrogen content of the hydrated alumina was calculated based on its chemical formula. Samples of the model mixtures were collected during construction. They are available for analysis, although no analysis has been performed to date.

The models were constructed and installed initially at the facilities of Niel F. Lampson, Inc. in Pasco, Washington, which is about 30 km from the Hanford site. Cased holes at that facility extended 3 m into the ground below the models to provide run tubes for long logging tools needing to extend below the tanks. A ceiling hoist about 9 m above the models lifted logging tools into the models. The location of the models off the Hanford Site simplified access to the models by commercial well logging companies, as well as expediting construction of the models.

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Appendix A

5% Moisture with 20.3-cm Casing (Model A) Detailed Data

Table A.1. Construction Summary for 5% Moisture Model with 20.3-cm Casing (Model A)

0.05 HI Moisture Model														
Model: A (8 in. casing)														
Project: Moisture Calibration Models														
Material Placement Data														
Requester: Robert E. Engelman														
Placed By: EA Clayton, AW Pearson, Clay O'Laughlin, Russ Randall														
Date Started: 6-28-94														
Date Completed: 6-29-94														
MIX DESIGN PARAMETERS PER MIXER BATCH														
Material Type	Weight Used (g)				Weight Fraction				TOTAL WEIGHT USED (g)					
Hydrated Alumina	10,410				0.0820				457254					
Tabular Alumina	0				0.0000									
Silica Sand (Ottawa)	116,564				0.9180				5119793.7					
Combined Total	126,974				1.0000				5577048 (12295 lb)					
Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (Inches)	Final Depth (Inches)	Lift Height (Inches)	Total Height (Inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Cumulat. Density (g/cc)	Lift Porosity	Cumul. Porosity
1	30 max	0.25	74.94	60.86	14.08	14.08	630122	630122	1014248	1014248	1.61	1.61	0.386	0.386
1	30 max	0.25	74.94	61.25	13.69	13.69	612669	612669	1014248	1014248	1.66	1.66	0.368	0.368
1	30 max	0.25	74.94	61.30	13.64	13.64	610431	610431	1014248	1014248	1.66	1.66	0.366	0.366
1	30 max	0.7	74.94	61.55	13.39	13.39	599243	599243	1014248	1014248	1.69	1.69	0.354	0.354
1	30 max	0.5	74.94	61.81	13.13	13.13	587607	587607	1014248	1014248	1.73	1.73	0.341	0.341
1	30 max	0.33	74.94	61.88	13.06	13.06	584474	584474	1014248	1014248	1.74	1.74	0.338	0.338
2	30 max	2.25	61.88	55.53	6.35	19.41	284182	868656	506938	1521186	1.78	1.75	0.319	0.332
3	30 max	1.2	55.53	48.72	6.81	26.22	304768	1173424	507036	2028222	1.66	1.73	0.365	0.340
3	30 max	0.4	48.72	48.71	6.82	26.23	305215	1173871	507036	2028222	1.66	1.73	0.366	0.341
3	30 max	0.4	48.71	48.98	6.55	25.96	293132	1161788	507036	2028222	1.73	1.75	0.340	0.334
3	30 max	0.4	48.98	48.99	6.54	25.95	292685	1161340	507036	2028222	1.73	1.75	0.339	0.334
3	30 max	0.5	48.99	49.00	6.53	25.94	292237	1160893	507036	2028222	1.74	1.75	0.338	0.333
3	35 max	2.25	49.00	49.13	6.40	25.81	286419	1155075	507036	2028222	1.77	1.76	0.324	0.330
4	35 max	2	49.13	42.69	6.44	32.25	288209	1443284	506910	2535132	1.76	1.76	0.329	0.330
5	35 max	2	42.69	36.21	6.48	38.73	289999	1733284	506987	3042119	1.75	1.76	0.333	0.330
6	40 max	1	36.21	29.60	6.61	45.34	295917	2029101	506949	3549068	1.71	1.75	0.346	0.333
6	45 max	0.8	36.21	29.71	6.50	45.23	290895	2024178	506949	3549068	1.74	1.75	0.335	0.331
6	45 max	0.75	36.21	29.78	6.43	45.16	287762	2021045	506949	3549068	1.76	1.76	0.328	0.330
7	45 max	0.75	29.78	23.23	6.55	51.71	293132	2314178	506904	4055972	1.73	1.75	0.340	0.331
7	45 max	1	29.78	23.29	6.49	51.65	290447	2311492	506904	4055972	1.75	1.75	0.334	0.330
7	45 max	1.12	29.78	23.33	6.45	51.61	288657	2309702	506904	4055972	1.76	1.76	0.330	0.330
8	45 max	2	23.33	16.87	6.46	58.07	289104	2598807	507109	4563081	1.75	1.76	0.331	0.330
8	45 max	0.75	23.33	16.92	6.41	58.02	286867	2596569	507109	4563081	1.77	1.76	0.325	0.329
9	45 max	2.25	16.92	10.47	6.45	64.47	288657	2885226	506943	5070024	1.76	1.76	0.330	0.329
10	45 max	3.17	10.47	4.04	6.43	70.90	287762	3172988	507024	5577048	1.76	1.758	0.328	0.329
Remarks														
Lift 1 used 8 mixer batches. Lifts 2-10 used 4 mixer batches.														

A.1

Table A.2. Material Depth Averages for 5% Moisture Model with 20.3-cm Casing (Model A)

0.05 HI Moisture Model Material Placement Measurements (Averages) Model: A (8 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL	COMMENTS
1	#DIV/0!	60.86	#DIV/0!	60.86	14.08	#DIV/0!	#DIV/0!	Increased pressure slowly then decreased it slowly to zero.
1	#DIV/0!	61.25	#DIV/0!	61.25	13.69	#DIV/0!	#DIV/0!	Increased pressure slowly then decreased it slowly to zero.
1	#DIV/0!	61.30	#DIV/0!	61.30	13.65	#DIV/0!	#DIV/0!	Increased pressure slowly then decreased it slowly to zero.
1	#DIV/0!	61.55	#DIV/0!	61.55	13.39	#DIV/0!	#DIV/0!	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
1	61.75	61.57	61.95	61.81	13.13	61.75	13.25	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
1	61.85	61.64	62.00	61.88	13.06	61.83	13.17	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
2	55.27	55.24	55.77	55.53	6.35	55.42	6.41	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 4 cycles.
3	#DIV/0!	48.72	#DIV/0!	48.72	6.81	#DIV/0!	#DIV/0!	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
3	#DIV/0!	48.71	#DIV/0!	48.71	6.82	#DIV/0!	#DIV/0!	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
3	48.61	48.75	49.23	48.98	6.55	48.86	6.56	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
3	48.63	48.77	49.24	48.99	6.53	48.88	6.55	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
3	48.65	48.80	49.24	49.00	6.52	48.89	6.53	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
3	49.23	48.64	49.33	49.13	6.40	49.07	6.36	Increased pressure slowly, synched vibrators, then decreased it slowly to zero.
4	42.38	42.25	43.02	42.69	6.44	42.55	6.52	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 4 cycles.
5	35.84	35.92	36.49	36.21	6.48	36.08	6.47	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 4 cycles.
6	29.36	29.66	29.86	29.60	6.61	29.63	6.46	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 4 cycles.
6	29.48	29.33	29.99	29.71	6.50	29.60	6.48	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 3 cycles.
6	29.52	29.58	29.99	29.78	6.42	29.70	6.39	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 3 cycles.
7	22.94	22.99	23.46	23.23	6.37	23.13	6.50	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 4 cycles.
7	22.98	23.04	23.53	23.29	6.31	23.18	6.44	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 3 cycles.
7	23.09	23.03	23.57	23.33	6.27	23.23	6.40	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 3 cycles.
8	16.67	16.66	17.06	16.87	6.46	16.79	6.44	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 8 cycles.
8	16.77	16.69	17.10	16.92	6.41	16.85	6.38	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 3 cycles.
9	10.25	10.24	10.67	10.47	6.45	10.38	6.47	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 12 cycles.
10	3.77	3.77	4.28	4.04	6.42	3.94	6.44	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 16 cycles.
REMARKS:								

Table A.3. Material Depth Measurements for 5% Moisture Model with 20.3-cm Casing (Model A)

0.05 HI Moisture Model Material Placement Measurements Model: A (8 in. casing)																					
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	TOT. VIB. TIME FOR LFT.	PRES. (PSI)	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS								DEV. FROM LEVEL
						1	2	3	4	6	8	10	5	7	9	11	12	13	14	15	
1	28-Jun	5	0.25	0.25	30 max				60.19	60.38	61.63	61.25									0.60
1	28-Jun	NA	0.25	0.5	30 max				60.38	61.56	61.81	61.25									0.54
1	28-Jun	NA	0.25	0.75	30 max				60.50	61.56	61.81	61.31									0.49
1	28-Jun	NA	0.7	1.45	30 max				60.81	61.63	62.13	61.63									0.47
1	28-Jun	NA	0.5	1.95	30 max	62.19	61.88	61.19	60.88	61.63	62.19	61.56	61.50	61.63	62.38	61.81	62.19	61.81	62.00	62.25	0.41
1	28-Jun	NA	0.33	2.28	30 max	62.25	62.00	61.31	61.00	61.69	62.25	61.63	61.50	61.69	62.50	61.81	62.19	61.88	62.00	62.44	0.41
2	28-Jun	5	2.25	2.25	30 max	55.50	55.25	55.06	55.13	55.06	55.44	55.31	55.44	55.19	56.06	55.94	55.63	56.56	55.63	55.69	0.40
3	28-Jun	5	1.2	1.2	30 max				49.00	48.44	49.06	48.38									0.31
3	28-Jun	NA	0.4	1.6	30 max				48.44	48.94	49.06	48.38									0.30
3	28-Jun	NA	0.4	2	30 max	48.69	48.44	48.69	49.00	48.44	49.13	48.44	49.25	48.63	49.50	48.94	48.94	49.63	49.25	49.69	0.41
3	28-Jun	NA	0.4	2.4	30 max	48.75	48.38	48.75	49.00	48.50	49.06	48.50	49.25	48.69	49.50	49.00	48.94	49.69	49.25	49.63	0.40
3	28-Jun	NA	0.5	2.9	30 max	48.75	48.44	48.75	49.00	48.50	49.13	48.56	49.25	48.69	49.44	49.00	48.94	49.69	49.25	49.63	0.38
3	28-Jun	NA	2.25	5.15	35 max	48.88	49.19	49.63	48.81	48.56	48.63	48.56	49.06	48.75	49.63	49.00	49.56	48.94	49.81	49.88	0.45
4	28-Jun	5	2	2	35 max	42.25	42.38	42.50	42.00	42.25	42.50	42.25	42.56	42.81	43.25	42.94	43.06	42.75	43.25	43.56	0.44
5	29-Jun	5	2	2	35 max	35.94	35.94	35.63	35.69	36.25	35.81	35.94	36.13	36.63	36.38	36.13	36.69	36.56	36.69	36.69	0.37
6	29-Jun	5	1	1	40 max	29.69	29.00	29.38	29.38	29.06	29.81	28.81	29.50	29.56	29.94	29.25	30.19	30.25	29.75	30.44	0.46
6	29-Jun	NA	0.8	1.8	45 max	29.75	29.06	29.63	29.38	29.19	29.75	29.00	29.63	29.69	30.00	29.38	30.31	30.31	29.94	30.63	0.46
6	29-Jun	NA	0.75	2.55	45 max	29.89	29.19	29.89	29.44	30.19	29.69	29.00	29.63	29.75	30.00	29.44	30.31	30.31	29.94	30.50	0.41
7	29-Jun	5	0.75	0.75	45 max	23.06	23.19	22.56	22.75	23.00	23.13	23.06	22.94	23.31	23.44	23.19	23.63	23.94	23.63	23.63	0.36
7	29-Jun	NA	1	1.75	45 max	23.13	23.13	22.69	22.75	23.13	23.13	23.13	23.00	23.44	23.50	23.25	23.75	23.81	23.75	23.75	0.35
7	29-Jun	NA	1.12	2.87	45 max	23.19	23.19	22.88	22.81	23.13	23.13	23.06	23.06	23.44	23.50	23.38	23.75	23.88	23.81	23.75	0.33
8	29-Jun	5	2	2	45 max	16.69	16.69	16.63	16.56	16.63	16.63	16.81	16.75	16.88	16.88	17.00	17.00	17.25	17.19	17.50	0.26
8	29-Jun	NA	0.75	2.75	45 max	16.75	16.81	16.75	16.56	16.63	16.69	16.88	16.75	16.94	16.94	17.06	17.06	17.38	17.13	17.50	0.26
9	29-Jun	5	2.25	2.25	45 max	10.06	10.31	10.38	10.19	10.00	10.50	10.25	10.44	10.19	10.75	10.50	10.44	10.94	10.75	11.31	0.34
10	29-Jun	5	3.17	3.17	45 max	3.94	3.75	3.63	3.81	3.56	3.94	3.75	4.13	3.94	4.25	4.19	4.19	4.25	4.44	4.88	0.33
REMARKS:																					

Appendix B

20% Moisture with 20.3-cm Casing (Model B) Detailed Data

Table B.1. Construction Summary for 20% Moisture with 20.3-cm Casing (Model B)

0.20 HI Moisture Model
Model: B (8 in. casing)

Project: Moisture Calibration Models
Material Placement Data
Requester: Robert E. Engelman

Placed By: EA Clayton, AW Pearson, Clay O'Laughlin, Russ Randall
Date Started: 7-6-94
Date Completed: 7-8-94

MIX DESIGN PARAMETERS PER MIXER BATCH			TOTAL WEIGHT USED (g)	
Material Type	Weight Used (g)	Weight Fraction		
Hydrated Alumina	41,838	0.3358	1796097	
Tabular Alumina	0	0.0000	0	
Silica Sand (Ottawa)	82,754	0.6642	3552599.68	
Combined Total	124,592	1.0000	5348697	

Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (inches)	Final Depth (inches)	Lift Height (inches)	Total Height (inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Cumulat. Density (g/cc)	Lift Porosity	Cumul. Porosity
1	30 max	3.6	74.88	61.49	13.39	13.39	599243	599243	995760	995760	1.66	1.66	0.351	0.351
1	30 max	2.5	74.88	61.82	13.26	13.26	593425	593425	995760	995760	1.68	1.68	0.345	0.345
1	30 max	3.83	74.88	61.78	13.10	13.10	586264	586264	995760	995760	1.70	1.70	0.337	0.337
1	30 max	3.5	74.88	61.85	13.03	13.03	583132	583132	995760	995760	1.71	1.71	0.333	0.333
2	30 max	3.2	61.85	55.14	6.71	19.74	300293	883424	497405	1493165	1.66	1.69	0.353	0.340
2	30 max	5	61.85	55.25	6.60	19.63	295370	878501	497405	1493165	1.68	1.70	0.343	0.337
2	30 max	11.25	61.85	55.30	6.55	19.58	293132	876264	497405	1493165	1.70	1.70	0.338	0.335
3	30 max	5.75	55.30	48.63	6.67	26.25	298503	1174766	497454	1990619	1.67	1.69	0.349	0.339
3	30 max	8	55.30	48.63	6.67	26.25	298503	1174766	497454	1990619	1.67	1.69	0.349	0.339
4	35 max	2.1	48.63	41.96	6.67	32.92	298503	1473269	497473	2488092	1.67	1.69	0.349	0.341
4	35 max	2	48.63	42.01	6.62	32.87	296265	1471031	497473	2488092	1.68	1.69	0.345	0.340
4	35 max	1.83	48.63	42.02	6.61	32.86	295817	1470584	497473	2488092	1.68	1.69	0.344	0.340
4	35 max	1.66	48.63	42.06	6.57	32.82	294027	1468793	497473	2488092	1.69	1.69	0.340	0.339
5	35 max	4.83	42.06	35.48	6.58	39.40	294475	1763268	497568	2985660	1.69	1.69	0.340	0.339
5	35 max	2.42	42.06	35.53	6.53	39.35	292237	1761031	497568	2985660	1.70	1.70	0.335	0.338
6	40 max	2.9	35.53	28.97	6.56	45.91	293580	2054610	497533	3483193	1.69	1.70	0.338	0.338
6	40 max	1.4	35.53	29.02	6.51	45.86	291342	2052373	497533	3483193	1.71	1.70	0.333	0.338
7	40 max	5	29.02	22.41	6.61	52.47	295817	2348190	497563	3980756	1.68	1.70	0.343	0.338
7	40 max	1.5	29.02	22.43	6.59	52.45	294922	2347295	497563	3980756	1.69	1.70	0.341	0.338
8	40 max	7.66	22.43	15.87	6.56	59.01	293580	2640875	497533	4478289	1.69	1.70	0.338	0.338
9	40 max	3.9	15.87	9.28	6.59	65.60	294922	2935797	497450	4975739	1.69	1.69	0.342	0.338
10	40 max	4.25	9.28	4.41	4.87	70.47	217947	3153744	372958	5348697	1.71	1.696	0.332	0.338

REMARKS
1st lift used 11 mixer batches. Lifts 2-9 used 4 mixer batches. Lift 10 used 3 mixer batches.

B.1

Table B.2. Material Depth Averages for 20% Moisture with 20.3-cm Casing (Model B)

0.20 HI Moisture Model Material Placement Measurements (Averages) Model: B (8 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL.	COMMENTS
1	61.50	61.27	61.80	61.49	13.39	61.46	13.54	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
1	61.56	61.31	61.80	61.62	13.26	61.56	13.44	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
1	61.98	61.49	61.86	61.78	13.10	61.77	13.23	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
1	62.23	61.45	61.91	61.85	13.03	61.86	13.14	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
2	54.90	54.99	55.31	55.14	6.71	55.07	6.80	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
2	55.19	55.02	55.38	55.25	6.60	55.20	6.67	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
2	55.19	55.16	55.41	55.30	6.55	55.25	6.61	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
3	48.08	48.54	48.88	48.63	6.67	48.50	6.75	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
3	48.12	48.55	48.86	48.63	6.67	48.51	6.74	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
4	41.36	41.80	42.26	41.96	6.68	41.80	6.71	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
4	41.50	41.81	42.30	42.01	6.62	41.87	6.64	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
4	41.56	41.85	42.28	42.02	6.61	41.89	6.62	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
4	41.61	41.91	42.31	42.06	6.57	41.94	6.57	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
5	35.31	35.33	35.62	35.48	6.58	35.42	6.52	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 20 cycles.
5	35.31	35.36	35.70	35.53	6.53	35.46	6.48	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
6	28.63	28.66	29.25	28.97	6.57	28.85	6.61	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 20 cycles.
6	28.65	28.72	29.31	29.02	6.52	28.89	6.57	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
7	22.15	22.17	22.63	22.41	6.61	22.32	6.58	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 30 cycles.
7	22.17	22.19	22.66	22.43	6.58	22.34	6.55	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
8	15.71	15.63	16.06	15.87	6.56	15.80	6.54	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 30 cycles.
9	9.10	9.02	9.47	9.28	6.60	9.20	6.60	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
10	4.13	4.11	4.67	4.41	4.86	4.30	4.89	Reduced lift size to 3 batches of 124592 g. Same vib. technique - 20 cycles.
REMARKS:								

Table B.3. Material Depth Measurements for 20% Moisture with 20.3-cm Casing (Model B)

0.20 HI Moisture Model Material Placement Measurements Model: B (8 in. casing)																							
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	CUM. VIB. TIME FOR TANK	PRES. (PSI)	NO. OF VIB. CYCLES	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS									DEV. FROM LEVEL
							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	6-Jul	5	3.6	3.6	30 max	10	61.63	61.50	61.38	61.06	60.94	61.63	61.44	61.31	61.06	61.81	61.56	61.75	61.75	61.25	62.31	0.34	
1	6-Jul	NA	2.5	6.1	30 max	10	61.50	61.63	61.56	61.00	61.00	61.75	61.50	61.19	61.50	61.94	61.88	61.88	61.63	61.88	62.50	0.37	
1	6-Jul	NA	3.83	9.93	30 max	10	61.69	61.94	62.31	61.19	61.19	61.94	61.63	61.13	61.44	62.13	61.94	62.13	61.63	62.19	62.25	0.39	
1	6-Jul	NA	3.5	13.43	30 max	10	62.00	62.06	62.63	61.06	61.50	62.06	61.19	60.94	62.19	62.06	61.75	62.13	61.50	62.69	62.00	0.51	
2	6-Jul	5	3.2	16.63	30 max	10	55.06	54.88	54.75	54.89	55.06	55.06	54.94	55.38	55.00	55.31	55.19	55.38	55.56	55.06	55.63	0.25	
2	6-Jul	NA	5	21.63	30 max	10	55.31	55.25	55.00	54.88	54.81	55.19	55.19	55.31	54.88	55.56	55.50	55.50	55.69	54.88	55.75	0.30	
2	7-Jul	NA	11.25	32.88	30 max	10	55.25	55.25	55.06	55.06	54.94	55.25	55.38	55.31	55.06	55.56	55.56	55.56	55.56	55.13	55.56	0.21	
3	7-Jul	5	5.75	38.63	30 max	10	48.31	47.81	48.13	48.63	48.44	48.63	48.44	49.06	48.63	49.00	48.69	49.00	48.75	48.75	49.13	0.35	
3	7-Jul	NA	8	46.63	30 max	10	48.31	47.81	48.25	48.63	48.50	48.69	48.38	49.13	48.56	49.06	48.63	48.94	48.63	48.81	49.13	0.35	
4	7-Jul	5	2.1	48.73	35 max	10	41.50	41.19	41.38	41.75	41.88	41.69	41.88	42.31	42.06	42.00	42.00	42.69	41.94	42.50	42.56	0.42	
4	7-Jul	NA	2	50.73	35 max	10	41.63	41.38	41.50	41.75	41.81	41.75	41.94	42.38	42.06	42.06	42.13	42.31	42.13	42.50	42.81	0.38	
4	7-Jul	NA	1.83	52.56	35 max	10	41.69	41.50	41.50	41.88	41.75	41.75	42.00	42.50	42.00	42.13	42.19	42.38	42.13	42.19	42.69	0.34	
4	7-Jul	NA	1.66	54.22	35 max	10	41.69	41.50	41.63	41.81	41.88	41.81	42.13	42.38	42.00	42.25	42.31	42.38	42.06	42.50	42.63	0.33	
5	7-Jul	5	4.83	59.05	35 max	20	35.63	35.31	35.00	35.25	35.44	35.25	35.38	36.00	35.50	35.63	35.25	35.88	35.31	35.44	35.94	0.28	
5	7-Jul	NA	2.42	61.47	35 max	10	35.56	35.31	35.06	35.31	35.38	35.38	35.38	36.00	35.56	35.75	35.38	35.94	35.50	35.56	35.94	0.26	
6	7-Jul	5	2.9	64.37	40 max	20	28.44	28.88	28.56	28.63	28.44	28.75	28.81	29.00	29.00	29.06	28.94	29.50	29.63	29.25	29.63	0.38	
6	7-Jul	NA	1.4	65.77	40 max	10	28.50	28.81	28.63	28.63	28.50	28.88	28.88	29.00	29.06	29.13	29.06	29.50	29.69	29.31	29.69	0.38	
7	7-Jul	5	5	70.77	40 max	30	22.06	22.00	22.38	22.25	21.94	22.44	22.06	22.56	22.25	22.63	22.31	22.88	22.75	22.63	23.00	0.32	
7	7-Jul	NA	1.5	72.27	40 max	10	22.06	22.00	22.44	22.25	21.88	22.50	22.13	22.50	22.31	22.63	22.44	22.81	22.94	22.63	23.00	0.32	
8	7-Jul	5	7.66	79.93	40 max	30	15.63	15.69	15.81	15.63	15.44	15.75	15.69	16.00	15.88	16.00	15.88	16.31	16.06	16.13	16.19	0.23	
9	8-Jul	5	3.9	83.83	40 max	15	9.25	9.00	9.06	8.75	9.13	9.19	9.00	9.06	9.44	9.56	9.13	10.00	9.50	9.56	9.50	0.30	
10	8-Jul	5	4.25	88.08	45 max	20	4.19	4.06	4.13	3.94	4.19	4.13	4.19	4.38	4.69	4.44	4.44	4.88	4.88	4.75	4.88	0.32	
REMARKS:																							

Appendix C

12% Moisture with 20.3-cm Casing (Model C) Detailed Data

Table C.1. Construction Summary for 12% Moisture with 20.3-cm Casing (Model C)

0.12 HI Moisture Model															
Model: C (8 in. casing)															
Project: Moisture Calibration Models															
Material Placement Data															
Requester: Robert E. Engelman															
Placed By: EA Clayton, AW Pearson, Clay O'Laughlin															
Date Started: 6-15-94															
Date Completed: 6-20-94															
MIX DESIGN PARAMETERS PER LIFT															
Material Type		Weight Used (g)		Weight Fraction		TOTAL WEIGHT USED (g)									
Hydrated Alumina		49,224		0.1951											
Tabular Alumina		0		0.0000											
Silica Sand (Ottawa)		203,095		0.8049											
Combined Total		252,319		1.0000											
Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (inches)	Final Depth (inches)	Lift Height (inches)	Total Height (inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Cumulat. Density (g/cc)	Lift Porosity	Cumul. Porosity	
1	25	3	74.88	71.43	3.45	3.45	154398	154398	251609	251609	1.63	1.63	0.372	0.372	
2	25	3	71.43	68.36	3.07	6.52	137392	291790	251539	503148	1.83	1.72	0.294	0.335	
3	25	4	68.36	65.10	3.26	9.78	145895	437684	251294	754442	1.72	1.72	0.336	0.335	
3	30	3	65.10	65.21	3.15	9.67	140972	432762	251294	754442	1.78	1.74	0.313	0.328	
4	30	3	65.21	61.99	3.22	12.89	144105	576866	251519	1005961	1.75	1.74	0.327	0.328	
5	30	3	61.99	58.61	3.38	16.27	151265	728131	251572	1257533	1.66	1.73	0.359	0.334	
5	30	3	58.61	58.66	3.33	16.22	149027	725894	251572	1257533	1.69	1.73	0.349	0.332	
5	25	4	58.66	58.70	3.29	16.18	147237	724104	251572	1257533	1.71	1.74	0.341	0.331	
5	20	4	58.70	58.70	3.29	16.18	147237	724104	251572	1257533	1.71	1.74	0.341	0.331	
5	35	4	58.70	58.71	3.28	16.17	146790	723656	251572	1257533	1.71	1.74	0.339	0.330	
6	30	5	58.71	55.53	3.18	19.35	142315	865971	251462	1508995	1.77	1.74	0.319	0.328	
7	30	5	55.53	52.28	3.25	22.60	145447	1011418	251700	1760695	1.73	1.74	0.333	0.329	
7	30	3	52.28	52.30	3.23	22.58	144552	1010523	251700	1760695	1.74	1.74	0.329	0.328	
7	35	3	52.30	52.34	3.19	22.54	142762	1008733	251700	1760695	1.76	1.75	0.320	0.327	
8	35	4	52.34	49.08	3.26	25.80	145895	1154627	251855	2012550	1.73	1.74	0.335	0.328	
8	35	3	49.08	49.15	3.19	25.73	142762	1151495	251855	2012550	1.76	1.75	0.320	0.326	
9	35	5	49.15	45.92	3.23	28.96	144552	1296047	251611	2264161	1.74	1.75	0.329	0.327	
10	35	5	45.92	42.75	3.17	32.13	141867	1437914	251913	2516074	1.78	1.75	0.315	0.325	
11	35	15	42.75	39.53	3.22	35.35	144105	1582019	251714	2767788	1.75	1.75	0.327	0.326	
12	40	3	39.53	36.30	3.23	38.58	144552	1726571	251772	3019560	1.74	1.75	0.329	0.326	
13	40	4	36.30	33.04	3.26	41.84	145895	1872466	251789	3271349	1.73	1.75	0.335	0.326	
13	40	3	33.04	33.12	3.18	41.76	142315	1868885	251789	3271349	1.77	1.75	0.318	0.325	
14	40	4	33.12	29.92	3.20	44.96	143210	2012095	251700	3523049	1.76	1.75	0.322	0.325	
15	40 max	0.5	29.92	26.65	3.37	48.33	150818	2162912	251743	3774792	1.67	1.75	0.357	0.327	
15	40	3	26.65	26.70	3.22	48.18	144105	2156200	251743	3774792	1.75	1.75	0.327	0.325	
16	40	4	26.70	23.56	3.14	51.32	140524	2296724	251725	4026517	1.79	1.75	0.309	0.324	
17	40	4	23.56	20.33	3.23	54.55	144552	2441276	251729	4278246	1.74	1.75	0.329	0.324	
18	40	4	20.33	17.21	3.12	57.67	138629	2580906	251685	4529931	1.80	1.76	0.305	0.323	
19	40	4	17.21	13.97	3.24	60.91	145000	2725905	251791	4781722	1.74	1.75	0.331	0.324	
20	40	5	13.97	10.81	3.16	64.07	141419	2867325	251785	5033507	1.78	1.76	0.314	0.323	
21	40	5	10.81	7.60	3.21	67.28	143007	3010332	251668	5285175	1.76	1.76	0.322	0.323	
22	40	5	7.60	4.37	3.23	70.51	143902	3154884	251747	5536922	1.75	1.755	0.326	0.323	
Minimum		1.63													
Maximum		1.80													
Average		1.78													
Standard Deviation		0.03762839													
REMARKS															
Vibrators 2 and 3 switched after lift 9.															

C.1

Table C.2. Material Depth Averages for 12% Moisture with 20.3-cm Casing (Model C)

0.12 Hl Moisture Model Material Placement Measurements (Averages) Model: C (8 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL.	COMMENTS
1	71.10	71.83	71.36	71.43	3.45	71.43	3.45	Vibrator 3 didn't start until 1:45 into vibration time.
2	68.38	68.46	68.30	68.36	3.08	68.38	3.05	
3	65.04	64.99	65.18	65.10	3.25	65.07	3.31	
3	65.02	65.02	65.38	65.21	3.15	65.14	3.24	Vibrated again due to low bulk density.
4	61.63	61.90	62.17	61.99	3.22	61.90	3.24	
5	58.52	58.56	58.67	58.61	3.38	58.58	3.31	
5	58.61	58.56	58.74	58.66	3.32	58.64	3.26	Vibrated again due to low bulk density.
5	58.54	58.56	58.82	58.70	3.29	58.64	3.25	Vibrated again due to low bulk density.
5	58.54	58.58	58.82	58.70	3.29	58.65	3.25	Vibrated again due to low bulk density.
5	58.48	58.61	58.85	58.71	3.27	58.65	3.25	Vibrated again due to low bulk density.
6	55.23	55.36	55.73	55.53	3.18	55.44	3.21	
7	51.92	52.13	52.49	52.28	3.26	52.18	3.26	
7	51.98	52.13	52.51	52.30	3.23	52.20	3.24	Vibrated again to try to increase compaction.
7	51.94	52.13	52.60	52.34	3.19	52.22	3.22	Vibrated again to try to increase compaction.
8	48.69	48.86	49.33	49.08	3.27	48.96	3.26	Significant depression at tank wall adjacent to vibrator 3.
8	48.65	48.82	49.50	49.15	3.20	48.99	3.24	Significant depression at tank wall adjacent to vibrator 3.
9	45.36	45.64	46.28	45.92	3.22	45.76	3.23	Significant depression at tank wall adjacent to vibrator 3.
10	42.44	42.49	42.99	42.75	3.18	42.64	3.12	Signif depression at wall adjacent to vib 2 (vibs 3 & 2 were switched).
11	39.00	39.24	39.88	39.53	3.22	39.37	3.27	Ran vibs 3 different times for Bob Brandt (vib. spec.) to make meas.
12	35.90	36.22	36.49	36.30	3.23	36.20	3.17	
13	32.67	32.88	33.27	33.04	3.26	32.94	3.27	Tank wall depressions at points 7 & 12.
13	32.67	32.83	33.44	33.12	3.18	32.98	3.22	Tank wall depressions at points 7 & 12.
14	29.63	29.68	30.15	29.92	3.20	29.82	3.16	Turned vibrators off slowly. Tank wall depressions at points 7 and 14.
15	26.17	26.49	26.73	26.55	3.36	26.46	3.36	Slowly increased pressure to 40 psi then slowly decreased it to 0.
15	26.33	26.55	26.91	26.70	3.22	26.60	3.22	Slowly increased to 40 psi, kept it there, then slowly decreased to 0.
16	23.39	23.36	23.73	23.56	3.13	23.49	3.10	Opnd & clsd master air valve slwly at start and end of vib, respectively.
17	20.29	20.17	20.43	20.33	3.23	20.30	3.19	Opnd & clsd master air valve slwly at start and end of vib, respectively.
18	17.11	17.16	17.28	17.21	3.12	17.18	3.12	Opnd & clsd master air valve slwly at start and end of vib, respectively.
19	14.06	13.92	13.96	13.97	3.24	13.98	3.20	Opnd & clsd master air valve slwly at start and end of vib, respectively.
20	10.81	10.74	10.84	10.81	3.17	10.80	3.19	Opnd & clsd master air valve slwly at start and end of vib, respectively.
21	7.54	7.46	7.70	7.60	3.21	7.56	3.23	
22	4.29	4.20	4.48	4.37	3.23	4.32	3.24	
REMARKS:								

Table C.3. Material Depth Measurements for 12% Moisture with 20.3-cm Casing (Model C)

0.12 HI Moisture Model Material Placement Measurements Model: C (8 in. casing)																				
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	PRES. (PSI)	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS								STAN. DEV. (IN)
					1	2	3	4	6	8	10	5	7	9	11	12	13	14	15	
1	15-Jun	10	3	25	71.06	71.19	71.06	72.13	71.81	71.81	71.56	71.44	69.81	71.81	71.81	71.69	71.13	71.94	71.25	0.55
2	15-Jun	10	3	25	68.38	68.50	68.25	68.50	68.38	68.50	68.44	68.31	68.06	68.19	68.69	68.38	68.44	68.00	68.31	0.17
3	15-Jun	10	4	25	65.25	65.63	64.25	64.44	65.06	64.88	65.56	64.88	65.31	65.44	65.13	65.00	65.44	64.88	65.38	0.38
3	"	NA	3	30	65.13	65.50	64.44	64.56	65.19	64.69	65.63	64.88	65.31	65.44	65.13	65.50	65.69	65.50	65.56	0.39
4	15-Jun	10	3	30	61.75	61.88	61.25	61.63	61.88	61.94	62.13	61.75	61.88	62.38	62.19	62.25	62.19	62.13	62.56	0.32
5	15-Jun	5	3	30	58.94	58.63	58.00	58.56	58.38	58.81	58.50	58.81	57.75	59.63	58.44	59.25	58.56	58.44	58.44	0.44
5	"	NA	3	30	58.69	58.50	58.63	58.50	58.31	58.88	58.56	58.81	57.94	59.25	58.44	59.19	58.69	58.88	58.69	0.32
5	"	NA	4	25	58.63	58.50	58.50	58.56	58.31	58.81	58.56	58.81	58.44	59.38	58.56	59.19	58.50	58.75	58.94	0.28
5	16-Jun	NA	5	20	58.63	58.50	58.50	58.56	58.38	58.81	58.56	58.81	58.50	59.25	58.56	59.13	58.75	58.63	58.94	0.24
5	"	NA	4	35	58.50	58.31	58.63	58.56	58.38	58.88	58.63	58.75	58.75	59.19	58.50	59.19	58.88	58.63	58.94	0.25
6	"	5	5	30	55.38	55.31	55.00	55.13	55.50	55.25	55.56	55.50	55.63	55.69	55.63	55.69	55.88	55.88	55.94	0.27
7	"	5	5	30	51.88	51.81	52.06	52.19	52.06	52.50	51.75	52.50	52.13	52.75	51.88	52.88	52.19	52.56	53.00	0.39
7	"	NA	3	30	51.94	51.81	52.19	52.19	52.06	52.50	51.75	52.44	52.13	52.88	52.00	52.81	52.31	52.44	53.06	0.38
7	"	NA	3	35	51.88	51.50	52.44	52.19	52.00	52.38	51.94	52.31	52.31	52.81	52.00	53.00	52.63	52.69	53.06	0.43
8	"	5	4	35	48.75	48.56	48.75	48.88	48.94	49.00	48.63	49.13	49.19	49.25	48.88	49.44	49.31	49.75	49.69	0.35
8	"	NA	4	35	48.50	48.50	48.94	48.88	48.81	48.94	48.63	49.25	49.44	49.38	48.94	49.63	49.56	50.00	49.81	0.46
9	"	5	6	35	45.19	45.13	45.75	46.13	45.25	45.81	45.38	46.50	45.81	46.44	45.75	46.63	46.13	47.06	45.88	0.55
10	"	5	5	35	42.50	42.31	42.50	42.50	42.56	42.75	42.13	42.81	42.88	43.63	42.13	43.38	42.56	43.50	43.06	0.45
11	"	5	15	35	38.94	38.75	39.31	39.44	39.38	39.31	38.81	39.75	40.25	39.88	39.13	40.06	39.75	40.50	39.69	0.50
12	17-Jun	5	3	40	35.88	35.81	36.00	36.31	35.94	36.63	36.00	36.75	36.38	36.63	36.19	36.75	36.13	36.69	36.38	0.32
13	17-Jun	5	4	40	32.56	32.75	32.69	32.88	32.63	33.19	32.81	33.50	33.31	33.31	32.94	33.69	33.00	33.31	33.06	0.32
13	17-Jun	NA	3	40	32.50	32.69	32.81	32.94	32.56	33.06	32.75	33.88	33.81	33.38	32.88	33.75	33.38	33.38	33.06	0.44
14	17-Jun	5	4	40	29.63	29.75	29.50	29.75	29.69	29.63	29.63	30.25	30.38	30.06	29.69	30.19	30.25	30.19	30.19	0.29
15	17-Jun	5	0.5*	#0 max	26.25	26.19	26.06	26.50	26.69	26.50	26.25	26.63	27.06	26.81	26.06	26.75	27.00	26.50	27.06	0.33
15	17-Jun	NA	3	40	26.31	26.44	26.25	26.63	26.75	26.50	26.31	26.81	27.19	26.88	26.31	27.00	27.13	26.81	27.13	0.32
16	17-Jun	5	4	40	23.56	23.31	23.31	23.31	23.44	23.50	23.19	23.81	23.88	23.75	23.31	23.81	23.50	23.81	23.94	0.24
17	17-Jun	5	4	40	20.31	20.25	20.31	20.44	20.00	20.25	20.00	20.88	20.38	20.44	19.94	20.88	19.94	20.56	20.44	0.29
18	17-Jun	5	4	40	17.13	17.06	17.13	17.44	17.19	17.25	16.75	17.44	17.38	17.44	16.69	17.63	17.00	17.25	17.38	0.25
19	18-Jun	5	4	40	14.06	14.31	13.81	13.94	13.88	13.81	14.06	14.00	14.00	13.88	13.81	13.94	13.94	14.13	14.00	0.13
20	18-Jun	5	5	40	10.94	10.81	10.69	10.63	10.88	10.81	10.63	10.69	11.19	10.81	10.63	10.94	10.81	10.63	11.00	0.16
21	18-Jun	5	5	40	7.56	7.75	7.31	7.38	7.44	7.44	7.56	7.56	7.69	7.69	7.56	7.94	7.56	7.63	7.94	0.18
22	18-Jun	5	5	40	4.25	4.44	4.19	4.31	4.06	4.06	4.38	4.50	4.44	4.38	4.50	4.56	4.38	4.56	4.50	0.16
REMARKS: Each lift was mixed in two batches to attain proper mixing of materials.																				

Appendix D

40% Moisture with 20.3-cm Casing (Model D) Detailed Data

Table D.1. Construction Summary for 40% Moisture with 20.3-cm Casing (Model D)

0.40 HI Thin-Layer Model
Model: D (8 in. casing)

Project: Moisture Calibration Models
 Material Placement Data
 Requester: Robert E. Engelman

Placed By: EA Clayton, AW Pearson, Clay O'Laughlin, Russ Randall
 Date Started: 7-13-94
 Date Completed: 7-14-94

MIX DESIGN PARAMETERS PER MIXER BATCH						
Material Type	5% HI:	Weight Used (g)	Weight Fraction	40% HI:	Weight Used (g)	Weight Fraction
Hydrated Alumina		12,323	0.0943		100,122	0.8957
Tabular Alumina		0	0.0000		11,664	0.1043
Silica Sand (Ottawa)		118,310	0.9057		0	0.0000
Combined Total		130,633	1.0000		111,786	1.0000
						TOTAL WEIGHT USED (g)
						1302288
						109759
						3457628.61
						4869676

Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (inches)	Final Depth (inches)	Lift Height (inches)	Total Height (inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Lift Porosity
1	NA	NA	74.91	48.27	26.64	26.64	1195825	1195825	1859520	1859520	1.555	0.406
2	NA	NA	48.27	30.44	17.83	44.47	797946	1993771	1051899	2911419	1.318	0.496
3	NA	NA	30.44	3.63	26.81	71.28	1199828	3189994	1958257	4869676	1.632	0.376
Minimum			1.32									
Maximum			1.63									
Average			1.50									
Standard Deviation			0.13									

REMARKS

1st lift used 14.25 mixer batches, 2nd lift used 9.42 mixer batches, and 3rd lift used 15 mixer batches.

Table D.2. Material Depth Averages for 40% Moisture with 20.3-cm Casing (Model D)

0.40 HI Thin Layer Model Material Placement Measurements (Averages) Model: D (8 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL.	COMMENTS
1	48.17	48.30	48.30	48.27	26.64	48.26	26.65	Filled tank to -27" graduation with 14.25 mixer batches.
2	30.38	30.52	30.43	30.44	17.83	30.44	17.81	Lift contained 9.42 mixer batches (amount needed to fill to -45" graduation).
3	3.63	3.69	3.60	3.63	26.82	3.64	26.80	Lift contained 15 mixer batches (amount needed to fill tank to top).
REMARKS:								

Table D.3. Material Depth Measurements for 40% Moisture with 20.3-cm Casing (Model D)

0.40 HI Thin Layer Model Material Placement Measurements Model: D (8 in. casing)																						
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	CUM. VIB. TIME FOR TANK	PRES. (PSI)	NO. OF VIB. CYCLES	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS								DEV. FROM LEVEL
							1	2	3	4	6	8	10	5	7	9	11	12	13	14	15	
1	14-Jul	5	NA	NA	NA	NA	48.25	48.13	48.13	48.44	48.44	48.44	47.88	48.50	48.38	48.56	48.06	48.75	48.19	48.19	47.75	0.26
2	14-Jul	5	NA	NA	NA	NA	30.63	30.31	30.19	30.50	30.31	30.56	30.69	30.63	30.00	30.38	30.31	30.69	30.31	30.63	30.50	0.20
3	14-Jul	5	NA	NA	NA	NA	3.63	3.75	3.50	3.75	3.75	3.88	3.38	3.50	3.69	3.88	3.38	3.69	3.56	3.75	3.31	0.17
REMARKS: Lift #1 was -27" of a 5% HI mix (HA+OttawaSand). Lift #2 was -18" of 40% HI mix (HA+TA). Lift #3 was -27" of 5% HI mix (HA+Ottawa).																						

Appendix E

12% Moisture with 15.4-cm Casing (Model E) Detailed Data

Table E.1. Construction Summary for 12% Moisture with 15.4-cm Casing (Model E)

0.12 HI Moisture Model Model: E (6 in. casing)														
Project: Moisture Calibration Models Material Placement Data Requester: Robert E. Engelman										Placed By: EA Clayton, AW Pearson, Clay O'Laughlin Date Started: 6-22-94 Date Completed: 6- -94				
MIX DESIGN PARAMETERS PER LIFT														
Material Type		Weight Used (g)		Weight Fraction		TOTAL WEIGHT USED (g)								
Hydrated Alumina		49,224		0.1951										
Tabular Alumina		0		0.0000										
Silica Sand (Ottawa)		203,095		0.8049										
Combined Total		252,319		1.0000										
Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (inches)	Final Depth (inches)	Lift Height (inches)	Total Height (inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Cumulat. Density (g/cc)	Lift Porosity	Cumul. Porosity
1	25	4	75.00	71.72	3.28	3.28	147918	147918	251752	251752	1.70	1.70	0.344	0.344
2	25	4	71.72	68.46	3.26	6.54	147016	294934	251780	503532	1.71	1.71	0.340	0.342
2	25	4	68.46	68.57	3.15	6.43	142056	289974	251780	503532	1.77	1.74	0.317	0.331
3	25	5	68.57	65.35	3.22	9.65	145212	435186	251757	755289	1.73	1.74	0.332	0.331
3	25	4	65.35	65.44	3.13	9.58	141154	431127	251757	755289	1.78	1.75	0.312	0.325
3	20	5	65.44	65.14	3.43	9.86	154683	444656	251757	755289	1.63	1.70	0.373	0.345
3	20	4	65.14	65.27	3.30	9.73	148820	438794	251757	755289	1.69	1.72	0.348	0.336
3	20	10	65.27	65.26	3.31	9.74	149271	439245	251757	755289	1.69	1.72	0.350	0.337
3	25	4	65.26	65.34	3.23	9.66	145663	435637	251757	755289	1.73	1.73	0.334	0.332
3	25	4	65.34	65.37	3.20	9.63	144310	434284	251757	755289	1.74	1.74	0.327	0.330
4	30	3	65.37	62.13	3.24	12.87	146114	580398	251622	1006911	1.72	1.73	0.336	0.331
4	30	3	62.13	62.13	3.24	12.87	146114	580398	251622	1006911	1.72	1.73	0.336	0.331
4	25	4	62.13	62.17	3.20	12.83	144310	578595	251622	1006911	1.74	1.74	0.328	0.329
5	30	5	62.17	58.94	3.23	16.06	145663	724258	251727	1258638	1.73	1.74	0.334	0.330
5	30	4	58.94	59.03	3.14	15.97	141605	720199	251727	1258638	1.78	1.75	0.315	0.326
6	30	5	59.03	55.74	3.29	19.26	148369	868568	251768	1510406	1.70	1.74	0.346	0.330
6	30	6.5	55.74	55.77	3.26	19.23	147016	867215	251768	1510406	1.71	1.74	0.340	0.329
6	30	6.25	55.77	55.64	3.39	19.36	152879	873078	251768	1510406	1.65	1.73	0.365	0.333
6	20	5	55.64	55.63	3.40	19.37	153330	873529	251768	1510406	1.64	1.73	0.367	0.333
Broke up sand at least one foot down due to very uneven sand surface caused by a cracked vibrator mounting bracket in SE corner. Replaced bracket with a 3/4" thick L-bracket.														
6	30	5	55.63	55.79	3.24	19.21	146114	866313	251768	1510406	1.72	1.74	0.336	0.328
7	35	3.5	55.79	52.44	3.35	22.56	151075	1017388	251785	1762191	1.67	1.73	0.358	0.332
7	30	4.5	52.44	52.42	3.37	22.58	151977	1018290	251785	1762191	1.66	1.73	0.361	0.333
7	30	5	52.42	52.49	3.30	22.51	148820	1015133	251785	1762191	1.69	1.74	0.348	0.331
7	35	3	52.49	52.60	3.19	22.40	143859	1010173	251785	1762191	1.75	1.74	0.325	0.328
8	35	4	52.60	49.30	3.30	25.70	148820	1158993	251662	2013853	1.69	1.74	0.348	0.330
8	35	4	49.30	49.34	3.26	25.66	147016	1157189	251662	2013853	1.71	1.74	0.340	0.329
8	35	4	49.34	49.33	3.27	25.67	147467	1157840	251662	2013853	1.71	1.74	0.342	0.329
8	40	3	49.33	49.39	3.21	25.61	144761	1154934	251662	2013853	1.74	1.74	0.330	0.328
9	40	4	49.39	46.21	3.18	28.79	143408	1298343	251680	2265533	1.75	1.74	0.323	0.327
10	40	4	46.21	42.97	3.24	32.03	146114	1444457	251546	2517079	1.72	1.74	0.336	0.328
11	40	5	42.97	38.09	4.88	36.91	220073	1664530	377600	2894679	1.72	1.74	0.339	0.330
11	40	3	38.09	38.10	4.87	36.90	219622	1664079	377600	2894679	1.72	1.74	0.337	0.329
12	40	4.5	38.10	33.23	4.87	41.77	219622	1883702	377599	3272278	1.72	1.74	0.337	0.330
12	40	4	33.23	33.26	4.84	41.74	218269	1882349	377599	3272278	1.73	1.74	0.333	0.330
13	40	6	33.23	28.44	4.79	46.56	216015	2099716	377590	3649868	1.75	1.74	0.326	0.330
14	40	6	28.44	23.70	4.74	51.30	213760	2313476	377723	4027591	1.77	1.74	0.319	0.329
15	40	6	23.70	17.25	6.45	57.75	290876	2604352	503748	4531339	1.73	1.74	0.332	0.329
15	40	4	17.25	17.29	6.41	57.71	289072	2602548	503748	4531339	1.74	1.74	0.328	0.329
16	40	8	17.29	10.88	6.41	64.12	289072	2891620	503677	5035016	1.74	1.74	0.328	0.329
17	40	6	10.88	4.39	6.50	70.61	293131	3184299	503654	5538670	1.72	1.739	0.338	0.329

Table E.2. Material Depth Averages for 12% Moisture with 15.4-cm Casing (Model E)

0.12 HI Moisture Model Material Placement Measurements (Averages) Model: E (6 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL.	COMMENTS
1	71.71	71.82	71.68	71.72	3.28	71.74	3.26	
2	68.44	68.28	68.56	68.46	3.26	68.43	3.31	
2	68.79	68.38	68.57	68.57	3.16	68.58	3.15	
3	66.10	65.10	65.20	65.35	3.21	65.47	3.12	Very uneven surface. Vibrators not in synch for at least 1/3 vibration time.
3	66.25	64.85	65.43	65.44	3.13	65.51	2.92	Very uneven surface due to large amplitude sand motion caused by vibrators not in synch.
3	65.19	65.32	65.04	65.14	3.42	65.18	3.40	Vibrators not in synch but sand motion a lot less than previous tries.
3	65.67	65.28	65.11	65.27	3.30	65.36	3.23	Vibrators not in synch but sand motion a lot less than previous tries.
3	65.67	65.21	65.14	65.26	3.30	65.34	3.24	Dropped vib. 1 down to 10 psi to get vibs synched.
3	65.73	65.21	65.27	65.34	3.22	65.40	3.18	Welded 3/8" steel spacers to vibrator mounting brackets.
3	65.75	65.25	65.29	65.37	3.20	65.43	3.15	
4	61.67	62.00	62.36	62.13	3.24	62.01	3.42	
4	61.71	61.94	62.39	62.13	3.23	62.01	3.42	Vibrate lift again to get better compaction.
4	61.77	61.88	62.47	62.17	3.20	62.04	3.39	Vibrate lift again to get better compaction.
5	58.67	58.78	59.13	58.94	3.23	58.86	3.18	
5	58.59	59.14	59.32	59.03	3.15	59.01	3.02	Vibrate lift again to get better compaction.
6	54.98	55.39	56.20	55.74	3.29	55.52	3.49	Significant sand surface deformation adjacent vib. 1.
6	55.75	55.39	55.97	55.77	3.25	55.71	3.31	3 separate vibration times. 2nd & 3rd vibrations with 2 opp. vibs only.
6	55.50	55.18	55.93	55.64	3.38	55.54	3.48	3 separate vibration times. 2nd & 3rd vibrations with 2 opp. vibs only.
6	55.38	55.53	55.78	55.63	3.39	55.56	3.45	3 separate vibration times. 2nd & 3rd vibrations with 2 opp. vibs only.
6	55.84	55.61	55.85	55.79	3.24	55.77	3.25	*See remarks below.
7	52.58	52.16	52.53	52.44	3.34	52.42	3.34	Replaced NE vib. bracket with new 1/2" thick one due to large vib. movement.
7	52.46	52.25	52.49	52.42	3.37	52.40	3.13	Replace NE vib. mounting bracket w/ 1/2" bracket.
7	52.54	52.17	52.63	52.49	3.29	52.45	3.07	
7	52.56	52.31	52.75	52.60	3.19	52.54	3.22	
8	49.40	48.94	49.45	49.30	3.30	49.26	3.28	Replace SW & NW vibrator mounting brackets with 1/2" thick brackets.
8	49.75	48.80	49.46	49.34	3.26	49.34	3.21	
8	49.44	49.10	49.40	49.33	3.27	49.31	3.23	
8	49.56	49.02	49.52	49.39	3.21	49.36	3.18	Dips in surface near casing and tank wall adjacent to vibrators.
9	46.42	45.67	46.40	46.21	3.18	46.16	3.20	
10	43.09	42.44	43.18	42.97	3.24	42.90	3.26	
11	37.94	37.49	38.44	38.09	4.88	37.96	4.95	Increased lift size to 3 batches of 126159 g = 379377 g
11	38.04	37.47	38.45	38.10	4.86	37.99	4.92	
12	33.08	32.77	33.52	33.23	4.87	33.12	4.86	
12	33.17	32.67	33.59	33.26	4.84	33.14	4.84	
13	28.17	28.00	28.77	28.44	4.82	28.31	4.83	
14	23.42	23.32	23.99	23.70	4.75	23.57	4.74	
15	16.96	16.88	17.54	17.25	6.45	17.13	6.45	Increased lift size to 4 batches of 126159 g = 504638 g
15	16.98	16.88	17.61	17.29	6.41	17.16	6.42	
16	10.63	10.49	11.16	10.88	6.41	10.76	6.40	
17	4.13	4.08	4.62	4.38	6.50	4.28	6.48	Decide not to vibrate any more due to bracket failure.
REMARKS:								

Table E.3. Material Depth Measurements for 12% Moisture with 15.4-cm Casing (Model E)

0.12 HI Moisture Model Material Placement Measurements Model: E (6 in. casing)																					
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	PRES. (PSI)	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS								DEV. FROM LEVEL	
					1	2	3	4	6	8	10	5	7	9	11	12	13	14	15		
1	22-Jun	5	4	25	71.75	72.00	71.38	71.31	72.38	70.88	72.69	71.44	71.38	70.63	72.56	71.69	71.63	71.25	72.88	0.64	
2	22-Jun	5	4	25	68.25	68.56	68.50	68.44	67.69	68.31	68.69	68.63	68.38	68.44	68.63	68.69	68.56	68.44	68.69	0.25	
2	22-Jun	NA	3	25	68.81	68.88	68.69	68.44	68.13	68.31	68.63	68.63	68.50	67.94	68.50	68.63	68.63	69.13	68.63	0.28	
3	22-Jun	5	5	25	67.00	66.31	65.00	64.25	65.38	65.31	65.44	64.63	64.63	65.75	64.81	65.19	65.50	65.63	65.44	0.66	
3	22-Jun	NA	4	25	67.13	67.38	64.25	63.69	64.94	64.75	66.00	65.06	64.06	66.69	65.00	65.00	66.25	65.88	65.50	1.06	
3	22-Jun	NA	5	20	65.19	65.44	64.94	65.63	64.69	65.31	65.63	65.56	64.00	65.44	65.06	64.19	65.50	65.38	65.19	0.48	
3	22-Jun	NA	4	20	65.88	65.88	65.25	65.19	65.13	65.31	65.50	65.44	64.25	65.44	65.13	64.75	65.63	64.88	65.38	0.41	
3	22-Jun	NA	10	20	65.63	65.94	65.44	65.19	64.75	65.19	65.69	65.44	64.56	65.31	65.13	65.00	65.81	64.75	65.13	0.39	
3	23-Jun	NA	4	25	65.69	66.00	65.50	65.00	64.94	65.38	65.50	65.38	64.75	65.56	65.31	65.19	65.56	64.94	65.44	0.32	
3	23-Jun	NA	4	25	65.50	66.00	65.75	65.31	64.75	65.44	65.50	65.38	64.63	65.63	65.19	64.94	65.63	65.25	65.63	0.36	
4	23-Jun	5	3	30	61.81	61.56	61.83	61.25	62.19	62.44	62.13	61.56	62.31	62.75	62.63	62.56	62.56	62.50	62.00	0.45	
4	23-Jun	5	3	30	61.81	61.69	61.63	61.00	62.06	62.63	62.06	61.38	62.31	62.81	62.75	62.44	62.75	62.63	62.06	0.53	
4	23-Jun	5	4	25	61.88	61.75	61.69	60.94	61.81	62.56	62.19	61.25	62.63	63.38	62.81	62.31	62.75	62.44	62.19	0.61	
5	23-Jun	5	5	30	58.69	58.56	58.75	58.50	58.69	58.94	59.00	58.69	58.75	59.13	59.13	59.25	59.50	59.38	59.19	0.30	
5	23-Jun	NA	3	30	58.38	58.69	58.69	58.75	58.69	58.81	58.81	58.94	58.88	58.81	59.44	59.56	59.94	59.75	59.25	0.44	
6	23-Jun	5	5	30	54.31	55.38	55.25	55.38	55.25	55.19	55.75	55.94	55.25	56.25	55.88	55.88	56.94	57.13	56.31	0.70	
6	23-Jun	NA	6.5	30	55.44	55.94	55.88	55.19	54.94	55.50	55.94	55.31	55.00	56.13	56.63	55.44	56.31	56.63	56.31	0.54	
6	23-Jun	NA	6.25	30	55.25	55.63	55.63	55.94	54.13	55.19	55.44	57.13	53.31	56.63	55.94	54.13	58.00	56.06	56.25	1.15	
6	23-Jun	NA	5	20	55.38	55.88	54.88	54.63	56.50	55.44	55.56	54.94	56.25	56.38	55.44	56.88	55.44	55.69	55.19	0.62	
6	24-Jun	NA	7	30	55.94	55.63	55.94	55.50	55.94	55.56	55.44	55.63	55.88	56.00	56.00	56.25	55.88	55.69	55.50	0.23	
7	24-Jun	5	3.5	35	52.44	52.50	52.81	51.81	52.38	52.31	52.13	51.94	52.75	52.56	52.56	52.81	52.38	52.88	52.38	0.30	
7	24-Jun	NA	4.5	30	52.56	52.25	52.56	52.25	52.25	52.31	52.19	52.25	52.25	52.31	52.38	52.75	52.25	53.25	52.44	0.27	
7	24-Jun	NA	5	30	52.50	52.38	52.75	52.25	52.25	52.25	51.94	52.25	52.25	52.50	52.50	53.13	52.75	53.19	52.50	0.33	
7	24-Jun	NA	3	35	52.50	52.44	52.75	52.69	52.31	52.25	52.00	52.00	52.38	52.94	52.75	53.44	52.88	53.25	52.38	0.40	
8	24-Jun	5	4	35	49.19	49.25	49.75	49.13	49.00	48.94	48.69	49.25	49.00	49.44	49.19	49.56	49.81	49.75	49.56	0.32	
8	24-Jun	NA	4	35	49.50	49.63	50.13	49.00	49.06	48.63	48.50	49.06	49.19	49.56	49.25	49.81	49.81	49.50	49.50	0.43	
8	27-Jun	NA	4	35	49.31	49.25	49.75	49.19	49.13	49.13	48.94	49.13	49.31	49.13	49.31	49.88	49.63	49.69	49.13	0.27	
8	27-Jun	NA	3	40	49.31	49.56	49.81	48.88	49.44	49.06	48.69	49.00	49.44	49.75	49.25	49.81	49.56	49.88	49.44	0.35	
9	27-Jun	5	4	40	46.00	46.31	46.94	45.81	45.75	45.69	45.44	45.75	46.13	46.44	46.13	46.56	47.00	46.50	46.69	0.46	
10	27-Jun	5	4	40	42.63	43.00	43.63	42.69	42.25	42.38	42.44	42.88	42.69	42.88	43.00	43.31	43.69	43.38	43.63	0.46	
11	27-Jun	5	5	40	37.94	37.94	37.94	37.63	37.31	37.38	37.63	37.94	37.75	38.00	38.38	38.88	38.94	38.81	38.81	0.53	
11	27-Jun	5	3	40	37.81	37.94	38.38	37.50	37.44	37.31	37.63	37.94	37.94	38.00	38.31	39.00	38.81	38.81	38.75	0.53	
12	27-Jun	5	4.5	40	33.00	33.00	33.25	33.00	32.63	32.75	32.69	33.06	32.94	33.31	33.31	33.63	33.94	34.00	33.94	0.44	
12	27-Jun	NA	4	40	32.94	33.19	33.38	32.75	32.56	32.69	32.69	33.13	33.00	33.25	33.38	33.88	34.13	34.00	33.94	0.50	
13	27-Jun	5	6	40	28.00	28.19	28.31	28.13	27.88	28.00	28.00	28.56	28.38	28.56	28.50	28.94	29.00	28.94	29.25	0.41	
14	27-Jun	5	6	40	23.25	23.50	23.50	23.38	23.00	23.44	23.44	24.00	23.63	23.75	23.69	24.25	24.31	24.06	24.25	0.38	
15	27-Jun	5	6	40	16.94	17.00	16.94	16.94	16.69	16.94	16.94	17.69	17.38	17.50	17.31	17.75	17.69	17.31	17.69	0.34	
15	27-Jun	NA	4	40	16.94	17.00	17.00	17.00	16.63	16.94	16.94	17.75	17.38	17.50	17.44	17.94	17.75	17.38	17.75	0.38	
16	27-Jun	5	5	40	10.69	10.56	10.63	10.50	10.38	10.75	10.31	11.06	10.81	11.25	10.94	11.56	11.31	10.88	11.50	0.38	
17	28-Jun	5	6	40	4.06	4.13	4.19	4.06	3.94	4.13	4.19	4.38	4.38	4.56	4.44	4.69	4.94	4.50	5.06	0.32	
Total Vib. Time			183.25																		
REMARKS:																					
Lifts 1-10 were mixed as two separate batches of equal weight to attain proper mixing of materials.																					
Broke up sand at least one foot down due to very uneven sand surface caused by a cracked vibrator mounting bracket in SE corner. Replaced bracket with a 3/4" thick L-bracket.																					
Starting with lift 11, the lift size was increased to 3 batches of 126459 g.																					

Appendix F

5% Moisture with 15.4-cm Casing (Model F) Detailed Data

Table F.1. Construction Summary for 5% Moisture with 15.4-cm Casing (Model F)

0.05 HI Moisture Model Model: F (6 in. casing)																																																		
<div style="display: flex; justify-content: space-between;"> <div> Project: Moisture Calibration Models Material Placement Data Requester: Robert E. Engelman </div> <div> Placed By: EA Clayton, AW Pearson, Clay O'Laughlin, Russ Randall Date Started: 6-30-94 Date Completed: 7-1-94 </div> </div>																																																		
<table style="width:100%; border-collapse: collapse;"> <tr> <th align="left" colspan="4">MIX DESIGN PARAMETERS PER MIXER BATCH</th> <th align="right" colspan="2">TOTAL WEIGHT USED (g)</th> </tr> <tr> <td style="width:30%;">Material Type</td> <td style="width:20%;">Weight Used (g)</td> <td style="width:20%;">Weight Fraction</td> <td style="width:30%;"></td> <td style="width:10%;"></td> <td style="width:10%;"></td> </tr> <tr> <td>Hydrated Alumina</td> <td align="right">10,410</td> <td align="right">0.0820</td> <td></td> <td></td> <td align="right">457244</td> </tr> <tr> <td>Tabular Alumina</td> <td align="right">0</td> <td align="right">0.0000</td> <td></td> <td></td> <td align="right">0</td> </tr> <tr> <td>Silica Sand (Ottowa)</td> <td align="right">116,564</td> <td align="right">0.9180</td> <td></td> <td></td> <td align="right">5119678.06</td> </tr> <tr> <td>Combined Total</td> <td align="right">126,974</td> <td align="right">1.0000</td> <td></td> <td></td> <td align="right">5576922</td> </tr> </table>															MIX DESIGN PARAMETERS PER MIXER BATCH				TOTAL WEIGHT USED (g)		Material Type	Weight Used (g)	Weight Fraction				Hydrated Alumina	10,410	0.0820			457244	Tabular Alumina	0	0.0000			0	Silica Sand (Ottowa)	116,564	0.9180			5119678.06	Combined Total	126,974	1.0000			5576922
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Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (inches)	Final Depth (inches)	Lift Height (inches)	Total Height (inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Cumulat. Density (g/cc)	Lift Porosity	Cumul. Porosity																																				
1	25 max	1.12	74.94	56.02	18.92	18.92	853235	853235	1394651	1394651	1.63	1.63	0.376	0.376																																				
1	30 max	1.87	74.94	56.86	18.08	18.08	815354	815354	1394651	1394651	1.71	1.71	0.347	0.347																																				
1	30 max	1.5	74.94	56.96	17.98	17.98	810844	810844	1394651	1394651	1.72	1.72	0.344	0.344																																				
1	30 max	2.1	74.94	57.11	17.83	17.83	804080	804080	1394651	1394651	1.73	1.73	0.338	0.338																																				
1	30 max	1.75	74.94	57.15	17.79	17.79	802276	802276	1394651	1394651	1.74	1.74	0.337	0.337																																				
1	30 max	1.58	74.94	57.26	17.68	17.68	797315	797315	1394651	1394651	1.75	1.75	0.332	0.332																																				
2	30 max	2.25	57.26	50.83	6.43	24.11	289974	1087289	507041	1901692	1.75	1.75	0.333	0.333																																				
3	35 max	1.83	50.83	44.43	6.40	30.51	288621	1375909	506992	2408684	1.76	1.75	0.330	0.332																																				
4	35 max	3.33	44.43	38.16	6.27	36.78	282758	1658668	507086	2915770	1.79	1.76	0.316	0.329																																				
5	35 max	2	38.16	31.79	6.37	43.15	287268	1945936	508901	3422671	1.76	1.76	0.327	0.329																																				
6	40 max	3.2	31.79	25.49	6.30	49.45	284111	2230047	506863	3929534	1.78	1.76	0.319	0.328																																				
7	40 max	2.75	25.49	19.16	6.33	55.78	285464	2515511	506900	4436434	1.78	1.76	0.322	0.327																																				
8	40 max	2.58	19.16	12.80	6.36	62.14	286817	2802328	507009	4943443	1.77	1.76	0.325	0.327																																				
9	40 max	2.4	12.80	6.41	6.39	68.53	287520	3089847	506920	5450363	1.76	1.78	0.327	0.327																																				
10	40 max	2.4	6.41	4.86	1.55	70.08	69900	3159748	126559	5576922	1.81	1.765	0.309	0.328																																				
Minimum Maximum Average Standard Deviation																																																		
REMARKS 1st lift used 11 mixer batches. Lifts 2-9 used 4 mixer batches. Lift 10 used 1 mixer batch.																																																		

F.1

Table F.2. Material Depth Averages for 5% Moisture with 15.4-cm Casing (Model F)

0.05 HI Moisture Model Material Placement Measurements (Averages) Model: F (6 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL.	COMMENTS
1	55.25	55.91	56.37	56.02	18.92	55.84	19.16	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
1	56.42	56.53	57.18	56.86	18.08	56.71	18.29	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
1	56.50	56.69	57.28	56.96	17.98	56.82	18.18	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
1	56.86	56.80	57.35	57.11	17.83	57.00	18.00	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
1	56.96	56.80	57.40	57.15	17.79	57.05	17.95	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
1	57.04	56.91	57.52	57.26	17.68	57.16	17.84	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
2	50.21	50.62	51.17	50.83	6.43	50.67	6.49	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
3	43.86	44.21	44.75	44.43	6.41	44.27	6.40	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 5 cycles.
4	37.79	37.72	38.53	38.16	6.26	38.01	6.26	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
5	31.48	31.39	32.10	31.79	6.38	31.66	6.35	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
6	25.25	25.07	25.79	25.49	6.30	25.37	6.29	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
7	18.98	18.83	19.39	19.16	6.33	19.07	6.30	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
8	12.65	12.52	12.99	12.80	6.36	12.72	6.35	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
9	6.23	6.10	6.64	6.41	6.38	6.32	6.40	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 10 cycles.
10	4.75	4.69	4.98	4.86	1.56	4.81	1.52	Decreased lift size to one mixer batch. Used same vibrating technique as previous lift.
REMARKS:								

Table F.3. Material Depth Measurements for 5% Moisture with 15.4-cm Casing (Model F)

0.05 HI Moisture Model Material Placement Measurements Model: F (6 in. casing)																						
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	CUM. VIB. TIME FOR TANK	PRES. (PSI)	NO. OF VIB. CYCLES	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS								
							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DEV. FROM LEVEL
1	30-Jun	5	1.12	1.12	25 max	5	55.56	55.38	54.81	55.13	56.38	56.06	56.06	56.19	56.38	56.25	56.56	56.38	56.50	56.19	56.50	0.52
1	30-Jun	NA	1.87	2.99	30 max	5	56.81	56.44	56.00	56.00	56.81	56.44	56.88	56.94	56.81	57.19	57.19	57.19	57.83	57.00	57.50	0.46
1	30-Jun	NA	1.5	4.49	30 max	5	56.88	56.50	56.13	56.19	56.81	56.69	57.06	57.00	56.88	57.38	57.50	57.19	57.56	57.06	57.63	0.44
1	30-Jun	NA	2.1	6.59	30 max	5	57.19	56.88	56.50	56.50	56.88	56.81	57.00	57.19	56.94	57.50	57.31	57.13	57.75	57.31	57.69	0.36
1	30-Jun	NA	1.75	8.34	30 max	5	57.44	56.94	56.50	56.50	56.81	56.75	57.13	57.38	56.69	57.56	57.50	57.19	58.00	57.25	57.63	0.43
1	30-Jun	NA	1.58	9.92	30 max	5	57.44	57.00	56.69	56.69	56.81	56.94	57.19	57.38	56.88	57.69	57.56	57.25	58.00	57.50	57.88	0.41
2	30-Jun	5	2.75	12.67	30 max	10	50.38	49.94	50.31	50.31	50.56	51.06	50.56	50.88	50.75	51.50	51.06	51.31	51.44	51.19	51.25	0.46
3	30-Jun	5	1.83	14.5	35 max	5	44.00	43.88	43.69	44.31	44.25	44.13	44.13	44.81	44.38	44.81	44.44	44.44	45.25	45.06	44.81	0.43
4	30-Jun	5	3.33	17.83	35 max	10	37.75	37.75	37.88	37.94	37.31	37.81	37.81	38.50	37.69	38.50	38.44	38.81	38.88	38.44	38.94	0.49
5	30-Jun	5	3	20.83	35 max	10	31.38	31.58	31.50	31.56	31.19	31.50	31.31	31.94	31.69	32.06	31.75	32.50	32.44	32.19	32.25	0.40
6	1-Jul	5	3.2	24.03	40 max	10	25.13	25.25	25.38	25.38	24.81	25.19	24.88	25.75	25.25	25.75	25.44	25.94	26.19	26.94	26.06	0.41
7	1-Jul	5	2.75	26.78	40 max	10	18.88	19.08	19.00	18.88	18.63	19.00	18.81	19.13	18.94	19.31	19.25	19.69	19.69	19.63	19.50	0.33
8	1-Jul	5	2.58	29.36	40 max	10	12.63	12.69	12.63	12.44	12.50	12.69	12.44	12.75	12.75	13.06	12.50	13.31	13.31	13.38	12.88	0.31
9	1-Jul	5	2.4	31.76	40 max	10	6.08	6.31	6.31	6.13	5.94	6.13	6.19	6.38	6.25	6.56	6.38	7.00	7.00	6.81	6.75	0.33
10	1-Jul	5	2.4	34.16	40 max	10	4.75	4.75	4.75	4.69	4.63	4.75	4.69	4.94	4.75	5.00	4.81	5.38	5.38	5.00	4.56	0.24
REMARKS:																						

Appendix G

20% Moisture with 15.4-cm Casing (Model G) Detailed Data

Table G.1. Construction Summary for 20% Moisture Model (Model G) with 15.4-cm Casing

0.20 HI Moisture Model Model: G (6 in. casing)																																																																																																								
Project: Moisture Calibration Models Material Placement Data Requester: Robert E. Engelman																																																																																																								
Placed By: EA Clayton, AW Pearson, Clay O'Laughlin, Russ Randall Date Started: 7-11-94 Date Completed: 7-12-94																																																																																																								
<table> <tr> <th colspan="2">Material Type</th><th colspan="4">MIX DESIGN PARAMETERS PER MIXER BATCH</th><th colspan="9">TOTAL WEIGHT USED (g)</th></tr> <tr> <th colspan="2"></th><th colspan="2">Weight Used (g)</th><th colspan="2">Weight Fraction</th><th colspan="9"></th></tr> <tr> <td colspan="2">Hydrated Alumina</td><td colspan="2">41,838</td><td colspan="2">0.3358</td><td colspan="9">1796097</td></tr> <tr> <td colspan="2">Tabular Alumina</td><td colspan="2">0</td><td colspan="2">0.0000</td><td colspan="9">0</td></tr> <tr> <td colspan="2">Silica Sand (Ottawa)</td><td colspan="2">82,754</td><td colspan="2">0.6642</td><td colspan="9">3552599.68</td></tr> <tr> <td colspan="2">Combined Total</td><td colspan="2">124,592</td><td colspan="2">1.0000</td><td colspan="9">5348697</td></tr> </table>															Material Type		MIX DESIGN PARAMETERS PER MIXER BATCH				TOTAL WEIGHT USED (g)											Weight Used (g)		Weight Fraction											Hydrated Alumina		41,838		0.3358		1796097									Tabular Alumina		0		0.0000		0									Silica Sand (Ottawa)		82,754		0.6642		3552599.68									Combined Total		124,592		1.0000		5348697								
Material Type		MIX DESIGN PARAMETERS PER MIXER BATCH				TOTAL WEIGHT USED (g)																																																																																																		
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Lift Number	Vibrator Air Pres. (psi)	Vibration Time (min.)	Beginning Depth (inches)	Final Depth (inches)	Lift Height (inches)	Total Height (inches)	Lift Volume (cc)	Total Volume (cc)	Lift Mass (g)	Total Mass (g)	Lift Density (g/cc)	Cumulat. Density (g/cc)	Lift Porosity	Cumul. Porosity																																																																																										
1	30 max	6.7	74.94	81.75	13.19	13.19	594829	594829	995282	995282	1.67	1.67	0.347	0.347																																																																																										
1	30 max	2.5	74.94	81.93	13.01	13.01	586712	586712	995282	995282	1.70	1.70	0.338	0.338																																																																																										
2	30 max	3.2	61.93	55.32	6.61	19.62	298091	884803	497498	1492780	1.67	1.69	0.349	0.341																																																																																										
2	30 max	4.57	61.93	55.38	6.55	19.56	295385	882097	497498	1492780	1.68	1.69	0.343	0.339																																																																																										
2	30 max	6	61.93	55.43	6.50	19.51	293131	879842	497498	1492780	1.70	1.70	0.337	0.338																																																																																										
3	30 max	6.8	55.43	48.83	6.60	26.11	297640	1177483	497503	1990283	1.67	1.69	0.348	0.340																																																																																										
3	30 max	4.5	55.43	48.93	6.50	26.01	293131	1172973	497503	1990283	1.70	1.70	0.337	0.338																																																																																										
4	35 max	4	48.93	42.39	6.54	32.55	294934	1467907	497580	2487863	1.69	1.69	0.341	0.338																																																																																										
5	35 max	5.4	42.39	35.91	6.48	39.03	292229	1760136	497573	2985436	1.70	1.70	0.335	0.338																																																																																										
6	40 max	5.67	35.91	29.50	6.41	45.44	289072	2049208	497476	3482912	1.72	1.70	0.328	0.337																																																																																										
7	40 max	4.75	29.50	22.91	6.59	52.03	297189	2346397	497501	3980413	1.67	1.70	0.347	0.338																																																																																										
7	40 max	3.83	29.50	23.03	6.47	51.91	291778	2340985	497501	3980413	1.71	1.70	0.334	0.336																																																																																										
8	40 max	8	23.03	16.54	6.49	58.40	292680	2633665	497419	4477832	1.70	1.70	0.337	0.336																																																																																										
9	40 max	8	16.54	10.07	6.47	64.87	291778	2925442	497489	4975321	1.71	1.70	0.334	0.336																																																																																										
10	40 max	7.75	10.07	3.59	6.48	71.35	292229	3217671	497519	5472840	1.70	1.701	0.335	0.336																																																																																										
REMARKS 1st lift used 11 mixer batches. Lifts 2-9 used 4 mixer batches. Lift 10 used 3 mixer batches.																																																																																																								

G.1

Table G.2. Material Depth Averages for 20% Moisture Model with 15.4-cm Casing (Model G)

0.20 HI Moisture Model Material Placement Measurements (Averages) Model: G (6 in. casing)								
LIFT NUMBER	CENTER PIPE MEAN (IN) [A]	MIDDLE TANK MEAN (IN) [B]	OUTSIDE TANK MEAN (IN) [C]	OVERALL MEAN (IN) [D]	LIFT HT. FOR [D] (IN)	MEAN OF [A], [B], & [C] (IN)	LIFT HT. FOR PREV. COL.	COMMENTS
1	61.88	61.53	61.81	61.75	13.13	61.74	13.26	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
1	62.17	61.63	61.99	61.93	12.95	61.93	13.07	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
2	55.34	55.11	55.42	55.32	6.60	55.29	6.64	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
2	55.36	55.17	55.49	55.38	6.55	55.34	6.59	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
2	55.29	55.25	55.58	55.43	6.49	55.37	6.55	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
3	48.50	48.68	49.02	48.83	6.61	48.73	6.64	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 20 cycles.
3	48.75	48.75	49.08	48.93	6.51	48.86	6.48	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
4	42.11	42.10	42.64	42.39	6.54	42.28	6.58	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
5	35.60	35.58	36.20	35.91	6.47	35.79	6.49	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 20 cycles.
6	29.02	29.16	29.85	29.50	6.41	29.34	6.45	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 20 cycles.
7	22.63	22.66	23.15	22.91	6.59	22.81	6.54	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 20 cycles.
7	22.73	22.77	23.27	23.03	6.47	22.92	6.42	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 15 cycles.
8	16.46	16.35	16.67	16.54	6.49	16.49	6.43	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 30 cycles.
9	9.90	9.81	10.27	10.07	6.47	9.99	6.50	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 30 cycles.
10	3.23	3.30	3.88	3.59	6.48	3.47	6.52	Increased pressure slowly, synched vibrators, then decreased it slowly to zero - 30 cycles.
REMARKS:								

Table G.3. Material Depth Measurements for 20% Moisture Model with 15.4-cm Casing (Model G)

0.20 HI Moisture Model Material Placement Measurements Model: G (6 in. casing)																						
LIFT NUMBER	DATE	MIXING TIME (MIN)	VIBRATION TIME (MIN.)	CUM. VIB. TIME FOR TANK	PRES. (PSI)	NO. OF VIB. CYCLES	CENTER PIPE MEASUR			MIDDLE TANK MEASUREMENTS				OUTSIDE EDGE MEASUREMENTS								DEV. FROM LEVEL
							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	11-Jul	5	6.7	6.7	30 max	15	61.69	62.06	61.88	61.81	61.50	61.31	61.50	62.00	61.50	61.63	61.38	61.75	62.19	61.81	62.25	0.28
1	11-Jul	NA	5.9	12.6	30 max	15	62.06	62.06	62.38	61.69	61.69	61.50	61.63	61.69	61.81	61.63	61.94	62.69	61.75	62.19	62.19	0.32
2	11-Jul	5	6.27	18.87	30 max	15	55.38	55.13	55.50	55.06	55.19	55.31	54.88	55.06	55.56	55.50	55.25	55.75	55.44	55.63	55.19	0.23
2	11-Jul	NA	4.57	23.44	30 max	15	55.38	55.19	55.50	55.00	55.25	55.44	55.00	55.13	55.50	55.75	55.50	55.81	55.25	55.63	55.31	0.24
2	11-Jul	NA	6	29.44	30 max	15	55.25	55.13	55.50	55.06	55.19	55.56	55.19	55.06	55.50	55.94	55.69	56.00	55.56	55.56	55.31	0.29
3	11-Jul	5	6.8	36.24	30 max	20	48.75	48.44	48.31	48.31	48.88	48.88	48.63	48.44	49.31	49.25	49.06	49.56	48.63	48.94	49.00	0.36
3	11-Jul	NA	4.5	40.74	30 max	15	48.88	48.56	48.81	48.31	48.88	48.94	48.88	48.44	49.38	49.44	49.31	49.56	48.63	48.94	48.94	0.35
4	11-Jul	5	4	44.74	35 max	15	42.13	41.94	42.25	41.88	42.19	42.19	42.13	41.94	42.75	42.69	42.63	43.06	42.63	42.50	42.88	0.36
5	11-Jul	5	5.4	50.14	35 max	20	35.69	35.56	35.56	35.50	35.63	35.63	35.56	35.75	36.31	36.06	35.94	36.56	36.06	36.19	36.69	0.37
6	12-Jul	5	5.67	55.81	40 max	20	29.19	29.00	28.88	29.00	29.19	29.38	29.06	29.25	29.88	29.94	29.50	29.94	29.88	30.00	30.44	0.46
7	12-Jul	5	4.75	60.56	40 max	20	22.81	22.69	22.38	22.50	22.81	22.75	22.56	22.81	23.13	23.31	22.81	22.31	23.31	23.56	23.94	0.44
7	12-Jul	NA	3.83	64.39	40 max	15	22.94	22.69	22.56	22.69	22.81	22.88	22.69	22.81	23.19	23.31	22.88	23.25	23.31	23.50	23.94	0.36
8	12-Jul	5	8	72.39	40 max	30	16.63	16.44	16.31	16.44	16.31	16.38	16.25	16.50	16.50	16.69	16.50	16.63	16.75	16.75	17.06	0.21
9	12-Jul	5	8	80.39	40 max	30	10.13	9.81	9.75	9.69	9.81	10.00	9.75	9.94	10.25	10.38	10.19	10.19	10.31	10.44	10.44	0.26
10	12-Jul	5	7.75	88.14	40 max	30	3.25	3.19	3.25	3.38	3.06	3.38	3.38	3.88	3.63	4.00	3.81	3.69	4.13	3.75	4.13	-0.34
REMARKS:																						

G.3

Appendix H

Summary of All Models - Detailed Data

Table H.1. Summary for All Models

Results of Lab Analysis on Dry Materials											
Sand grain density (g/cc):			2.64								
Hydrated Alumina grain density (g/cc):			2.42								
Tabular Aluminum grain density (g/cc):			3.76								

Model ID	Casing Size (Inches)	Dates Model Constructed	Avg. Bulk Density (g/cc)	Average Porosity (pu)	Actual H	Vib. I-Bracket Dimensions (Inches)	Lift Size Heights (Inches)	Vibrator Pressure (psi)	Air Bag Frame Design	Vibration Technique	Comments
A: 5% HI	8	Start: 6/28/94 Finish: 6/29/94	1.758	0.329	0.050	1/2 X 3 X 3 X 15	Lift #1: 13.1 Lift #2-10: -6.4	25 (bottom) to 45 (top)	2nd design: No steel plates	At least 4 cycles per lift of increasing air pressure slowly, synching vibrators, then decreasing air pressure slowly.	First model where cycling technique was tried (suggested by Russ Randall).
F: 5% HI	6	Start: 6/30/94 Finish: 7/1/94	1.765	0.326	0.050	1/2 x 3 x 3 x 15	Lift #1: 17.7 Lift #2-9: -6.4 Lift #10: 1.6	25 (bottom) to 40 (top)	2nd design: No steel plates	At least 5 cycles per lift of increasing air pressure slowly, synching vibrators, then decreasing air pressure slowly.	
C: 12% HI	8	Start: 6/15/94 Finish: 6/20/94	1.755	0.323	0.119	3/8 x 3 x 3 x 15	-3.2	25 (bottom) to 40 (top)	1st design: Two 3/4" thick steel plates	Ran vibrators at constant pressure for intervals of 3 to 5 minutes. Varied pressure from 25 psi at bottom to 40 psi at top.	Bob Brandt (vibration specialist) checked out the setup. Recommended removing the steel plates in the air bag frame.
E: 12% HI	6	Start: 6/22/94 Finish: 6/28/94	1.739	0.329	0.117	3/8 changed to 1/2 thickness Other dim: 3 x 3 x 15	-3.2	25 (bottom) to 40 (top)	2nd design: No steel plates	Ran vibrators at constant pressure for intervals of 3 to 5 minutes. Varied pressure from 25 psi at bottom to 40 psi at top.	Vibrator mounting brackets developed cracks. 3/8" brackets were replaced one by one after they cracked with 1/2" brackets. At -20 in. into the model the sand was broken up at least 1 foot down due to very uneven sand surface (caused by cracked bracket(s)). First model built using 2nd air bag frame design (no steel plates).
B: 20% HI	8	Start: 7/6/94 Finish: 7/8/94	1.696	0.338	0.197	1/2 x 3 x 3 x 15	Lift #1: 13.0 Lift #2-9: -6.6 Lift #10: 4.9	30 (bottom) to 40 (top)	2nd design: No steel plates	At least 15 cycles per lift of increasing air pressure slowly, synching vibrators, then decreasing air pressure slowly.	
G: 20% HI	6	Start: 7/11/94 Finish: 7/12/94	1.701	0.336	0.198	1/2 x 3 x 3 x 15	Lift #1: 13.0 Lift #2-10: -6.5	30 (bottom) to 40 (top)	2nd design: No steel plates	At least 15 cycles per lift of increasing air pressure slowly, synching vibrators, then decreasing air pressure slowly.	
D: 40 % HI Thin Bed	8	7/14/94	1.555 (bot.) 1.318 (mid.) 1.632 (top)	0.406 (bot.) 0.496 (mid.) 0.376 (top)	0.051 (bot.) 0.409 (mid.) 0.053 (top)	1/2 x 3 x 3 x 15	Lift #1: -27 Lift #2: -18 Lift #3: -27	N/A	N/A	Model placed without vibration.	Model constructed by filling bottom 27" with 5% HI mix, leveling the top carefully, placing 18" of 40% HI mix, leveling, and filling the remaining 27" with the 5% mix. 40% mix contained hydrated alumina and tabular aluminum.

General Comments:											
<ul style="list-style-type: none"> One moisture sample was taken from every mixer batch and two from every lift (after vibration). (NOTE: On the last model (40% HI thin bed) samples were taken every other batch on the 3rd lift.) 15 depth to top of sand measurements were made for every lift: 3 against the center casing, 4 midway between the casing and the tank wall, and 9 against the tank wall. First air bag frame design consisted of two channel irons, braced together, with legs towards floor. Four air bags were bolted to the channel iron with valve stems faced down into channel iron void. A 3/4" thick steel plate, slightly larger than the... tank pallet was bolted to the tops of the air bags. Another 1/2" thick steel plate, sized to fit between the I-beams on the underside of the pallets, was spot welded on top of the first steel plate to prevent the tank from sliding. The air bags were... positioned so that they were directly beneath the vibrators. 2nd air bag frame design had the same understructure as the 1st one, but the steel plates were removed to reduce unwanted vibrational noise. Four small -1 ft. x 1 ft. plates were bolted to the airbags to support the pallet. The air bags had to be... positioned further out so that they were directly centered under the I-beams. 											

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