CALCULATING VOLUME REDUCTION FROM SUPERCOMPACTION

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ABSTRACT

Supercompaction, or high force compaction, of DAW is one of the better known and proven methods of volume reduction. Westinghouse Hittman first started crushing drums at the Ginna Nuclear Station in May of 1984. In any discussion of supercompaction, or even drum and box compaction in general, the issue of "actual" versus "calculated" volume reduction arises. After almost two full years of operating experience with the Westinghouse Hittman COMPACT-1 supercompactor, sufficient data has now been accumulated to allow a "actual" volume reduction to be determined given a specific waste type; i.e., for DAW, as well as for non-compactables, such as concrete, brick, asphalt roof material, and wood. "Actual" is defined as that volume reduction realized by the waste generator at the burial site over those methods currently being used. "Calculated" is defined as that volume reduction predicted by mathematical means.

WASTE STREAMS ANALYZED

Data for analysis has been accumulated on the following waste streams:

- o DAW - Dry Active Waste composed of varying percentages of plastic, paper, rubber gloves, and booties.
- o Tar Paper - Asphalt-impregnated felt with multiple layers of asphalt and stone layered on top of composite roofing materials.
- o Brick Rubble - High-fired bricks which had been pre-crushed into fragments that would pass through a 1" to 3/4" mesh screen.
- o Tile Rubble - High-fired hollow tile used in older commercial construction projects for inner portions of walls. Pre-crushed into fragments that would pass through a 1" to 3/4" mesh screen.
- o Wood - Fir used as structural material, roof planking, and for scaffolding. Wood was cut into lengths and stacked into the barrels.

All the data in TABLE III on the above waste streams was obtained from the crushing of 52-gallon barrels filled with waste segregated by the above categories. The filled barrels were then weighed to within a pound prior to being crushed. Each of the above categories had a minimum sample group of 60 barrels of a given waste type.

Definition of Volume Reduction

Volume reduction must be defined for a given application to be meaningful. Volume reduction can be defined relative to the before and after-crush height of the drum, density, and/or burial volume. If every waste processor crushed in the same container without changing the drum diameter, both height and/or density would be a valid comparison of volume reduction prior to placement in an overpack, or more accurately, a strong tight container. The actual volume reduction realized by the waste generator at the burial site can be a more meaningful measure of volume reduction, and will always be less than the volume reduction predicted by height, density, or volume differences. The difference is largely due to inefficiencies in packaging of the crushed drums to make them suitable for burial in the overpack.

Listed below are the various methods used to calculate volume reduction.

Volume Reduction Calculated Using Height:

$$\frac{\text{Beginning Height}}{\text{Final Height}} = \text{Volume Reduction}$$

Advantages:
- o Easy to calculate
- o Data easily obtained

Disadvantages:
- o Cannot be compared between different package types
- o Doesn't take into account radial expansion of the drum during crush which generally adds 1 inch to the circumference
- o Doesn't reflect overpack inefficiencies for disposal at the burial site

Volume Reduction Calculated Using Density:

$$\text{Beginning Density} = \frac{\text{Gross Bl. Wt. - Bl. Tare Wt.}}{\text{Beginning Bl. Volume (cu.ft.)}}$$

$$\text{Final Density} = \frac{\text{Gross Bl. Wt. - Bl. Tare Wt.}}{\text{Final Bl. Volume (cu.ft.)}}$$

$$\text{Final Bl. Volume} = \left[\frac{\text{Crushed Bl. Dia.}}{2}\right]^2 \pi \text{ (Final Ht)}$$

$$\text{Vol. Reduction} = \frac{\text{Final Density}}{\text{Beginning Density}} = \frac{\text{Beginning Bl. Vol.}}{\text{Final Bl. Volume}}$$

Advantages:
- o Density can be related to any package configuration
- o Density is relatively constant for a given material making volume reduction comparisons more predictable given a known material

- o Takes into consideration radial expansion of the crushed drum

Disadvantages:
- o Does not reflect packaging inefficiencies
- o Harder to calculate and obtain data that is meaningful

Volume Reduction Based on Burial Volume:

$$VR = \frac{(\text{Tl. No. of Drums Crushed})\ (\text{Burial Vol.})}{(\text{Tl. No. of Overpacks})\ (\text{Burial Vol.})}$$

Advantages:
- o Easy to calculate after a given project is complete
- o Truer measure of the volume reduction realized by the waste generator by taking into account packaging efficiency

Disadvantages:
- o Operators experience and judgement can greatly affect the packaging efficiency; hence, outcome of the volume reduction
- o Can only be calculated once a project is complete.

Each method of calculating volume reduction in Table I yields a different answer that can mislead a person who has not been given the basis for the comparison of volume reduction. I would recommend that when discussing volume reduction, the discussion always be prefaced by how volume reduction is going to be defined.

TABLE I

Comparison of Volume Reduction Calculation Methods

Barrel #1	Barrel #2
Barrel Weight: (Tare Wt. 30#) 262#	Barrel Weight: (Tare Wt. 30#) 215#
Barrel Height Before Crush: 35.75"	Barrel Height Before Crush: 35.75"
Barrel Height After Crush: 13.50"	Barrel Height After Crush: 12.00"

Volume Reduction Using Height: = 35.75"/13.50" = 2.65:1 Reduction Barrel #1

= 35.75"/12.00" = 2.98:1 Reduction Barrel #2

Volume Reduction Using Density $= \frac{(262-30)\#}{7.04\ ft^3} \quad \frac{(262-30)\#}{2.97\ ft^3} = 2.37:1$ Barrel #1

$= \frac{(215-30)\#}{7.04\ ft^3} \quad \frac{(215-30)\#}{2.64\ ft^3} = 2.67:1$ Barrel #2

Volume Reduction Based on Burial Volume: $= \frac{(\text{Original Vol. Before Compaction})}{(\text{Final Overpack Vol. After Compact})}$

$= \frac{[2] \times (7.5\ \text{cu.ft.})}{[1] \times (7.5\ \text{cu.ft.})} = \frac{15\ \text{cu.ft.}}{7.5\ \text{cu.ft.}} = 2:1$

Experience has shown that the best method of calculating volume reduction is using density. By having the waste generator give the type, size, and weight of the containers being used; the waste generators beginning density can be determined. The end density produced by supercompaction has very little variance thus allowing the user to make an accurate prediction of what the volume reduction will be.

Once a predicted volume reduction is calculated using density, the user must allow for possible packaging inefficiency resulting from placing the crushed drums in a limited volume container, i.e., the 55-gallon overpack. This leads into an important, if not the most important, variable to consider when using supercompaction services; the strong tight container selection, or overpack.

Strong Tight Container Selection (Overpack)

All containers sent to a burial site are assessed a burial volume in cubic feet by taking the outside dimensions at the outermost points of the container, then calculating a burial volume. The cost of the barrels or overpacks in the analysis below is not included because burial volume costs are a great deal more than the container costs, and container costs will vary considerably, depending on how they are purchased.

TABLE II

Sample Packaging Calculations

Packaging Method	Drum Tare Wt.	Net Waste Wt.	Inner Vol. Drum	No. Drums OvPak	Vol. Before Crush	Cost ft^3	Overpack Vol. at Burial	Total lbs DAW Buried	Dollars Pound
55-gal. Drums in 85-gal Overpacks	50	230	7.5	2	15 ft^3	35.7	11.6 ft^3	460	\$0.90/#
52-gal. Drums in 55-gal Overpacks	30	230	7.04	2	15 ft^3	35.7	7.5 ft^3	460	\$0.58/#

Because of the relatively large difference in cubic feet between overpacks when comparing 85-gallon versus 55-gallon drums the selection of overpacks based on economics, favors the 52-gallon drum as the drum to be crushed and placing it into a 55-gallon overpack for burial. If typical drum costs are considered, the costs further favor 52-gallon drums and 55-gallon overpacks. A 52-gallon drum costs about \$21, a 55-gallon drum costs about \$26, and an 85-gallon drum costs about \$63. Again assuming a 2:1 packaging efficiency, the total cost of materials for crushing 55-gallon drums will be approximately \$115/package of 2 crushed drums in 1 overpack. The total cost for crushing 52-gallon drums will be about \$68/package, or a difference of \$47/package, with little or no gain in the amount of DAW buried.

Obviously the 55-gallon barrel has more volume, bringing up the obvious question as to why little or no gain is made in the weight of DAW precompacted in the barrels. Experience has shown that when a precompactor for DAW is backfitted with a smaller diameter platten to allow precompaction in a 52-gallon drum, greater force per square inch of platten area will be exerted allowing for the higher density of waste in the 52-gallon drum versus the 55-gallon drum. (The difference in platten areas between a 19" versus a 21" platten is about 22%, more than offsetting the 6% difference in drum volume.) Because of the different area over which the same ram force is exerting it's pressure, higher precompaction density of DAW can be achieved with the same precompactor in a 52-gallon drum, more than offsetting the small volume difference.

Effects of Packaging Efficiency on Density

Supercompaction makes large gains in volume reduction not only due to it's high ram force, but by being able to overcome some of the inefficiencies of placing the actual waste material in the drum to start with. This is particularly true with materials such as wood, pipe, concrete, brick, as well as normal DAW materials. We have already seen that the lower the beginning density relative to the end density, the greater the volume reduction. If the beginning density is too low, the waste generator is not efficiently using the drums. If the density is too high, then at some point two supercompacted drums will not fit into the intended overpack. Where is the balance between too little or too much waste in the drum to be compacted. This is where the experience of those doing the supercompaction service can be of greatest service to the waste generator. Those providing the service should be expected to guide the waste generator on the optimum barrel weight for a given waste material. This consideration can make or break the economic payback for both the waste generator and the ones providing the service. Making claims of a 4:1 or 5:1 volume reduction with no restrictions on the beginning waste density can cause both parties to become disenchanted with supercompaction services.

Assuming at least a 2:1 volume reduction is desired, the maximum final density must be determined from the experience of the supercompaction operators. Divide the final density by the volume reduction factor desired, then multiply the beginning density calculated times the barrel volume that is to be crushed. This will give the maximum barrel weight that can be economically fed to the supercompactor. Obviously any barrel produced that is under this weight will also meet the volume reduction requirements, but the waste generator will not have used the drums to the best of their advantage. A condition of too low a drum weight is preferable over too high a drum weight. Also note that it may be impossible for the waste generator loading the drums to meet the optimum density. An example of this is wood. Note that in Table III an optimum weight of 177 pounds/drum is shown for wood. Experience has shown that one is more likely to get about 135 pounds. Because it is impractical to fit more wood into the drum due to the labor effort required, the supercompaction service pays back extra dividends to the waste generator by getting greater than a 2:1 volume reduction where present packaging methods are inefficient. The waste generator must weigh the effort required to obtain the recommended drum weight against the cost of crushing extra drums.

Effects of Overpack Packaging Efficiency

Overpack packaging efficiency from the standpoint of selecting the optimum container size has been discussed earlier. The point of this section is to show what effect properly sorting the crushed drums for optimum use of the overpack space, and the inefficiencies currently experienced have been. This ultimately leads to a discussion of the labor required to sort the crushed drums for maximum efficiency versus getting the job done in a timely manner.

DAW supercompaction jobs studied show a 2.12:1 to 2.56:1 volume reduction achieved prior to packaging in overpacks. After packaging in the overpacks a volume reduction of from 2:1 to 2.44:1 was actually experienced.

Non-compactables studied were all part of the same job involving 1156 drums and the crushed drums containing specific waste types were mixed in the overpack. The average volume reduction prior to packaging the waste in overpacks was 2.65:1. After packaging in the overpacks, the total volume reduction became 2.22:1.

TABLE III

Expected Versus Actual Beginning Drum Weights

	DAW	Tar Paper	Brick	Wood	Tile
Average Maximum Density Achievable* (Pounds/cubic foot)	65	66	105	50.2	108
Optimum Beginning Density (#/ft^3) Recommended by Dividing Above by 2	32.5	33	52.5	25.1	54
Resulting Optimum 52-Gallon Drum Wt. (Pounds)	259	262	400	177	410
Actual Avg. Density Experienced (Pounds/Cubic Foot)	29	29	51.2	14.6	57.6
Actual Avg. 52-Gallon Drum Weight (Pounds)	236	240	393	135	438
Actual Volume Reduction Achieved Before Before Packaging in Overpacks	$\frac{2.12}{1}$	$\frac{2.31}{1}$	$\frac{2.11}{1}$	$\frac{3.62}{1}$	$\frac{1.88}{1}$
Burial Volume Reduction Achieved	$\frac{2.0}{1}$	Combined Total Avg. Of Above Before:		$\frac{2.48}{1}$ After	$\frac{2.22}{1}$
Adjustment Factor to Allow For Calc. Actual Burial Vol. Reduction:	.94				.90

*For a 1000 ton press these figures are from 90 to 95 percent of the theoretical optimum density for a specific material

Westinghouse Hittman Nuclear Incorporated has, as a result of these studies, started to look at methods of sorting the pucks going into the overpacks to more efficiently utilize the existing space. Preliminary results show that a reasonable program could effectively improve the volume reduction at the burial site by as much as 20%, without changing the ram force. Drum sorting would also tend to make the "Burial Adjustment Factor" from Table III a constant for all waste types as the "Burial Adjustment Factor" is a measure of the overpack packaging efficiency.

"Actual" Method of Calculating Volume Reduction

The step-by-step method of predicting "actual" volume reduction using density calculation methods for the material being crushed is as follows:

- Calculate Optimum Crushed Barrel Weight:

  Using either theoretical or measured maximum density of the material being crushed, multiply the theoretical by (.9) or use maximum density achievable for known materials (Refer to Table III).

  Theoretical: (.9) (Lowest Theoretical Density)/(Vol. Red. Desired) = Optimum Beginning Density

  Measured Max. Density: (Measured Max. Density)/(Vol. Red. Desired) = Optimum Beginning Density

- Calculate Maximum Barrel Weight to be Crushed:

  [(Optimum Beginning Density)(Barrel Vol.)] + (Barrel Tare Wt.) = Maximum Crushed Barrel Weight

- o Calculate the Expected Max. Pounds Per Inch of Crushed Barrel Height:

  (Theoretical Density)(.9)(Barrel to be Crushed Vol.) = Max. Barrel Wt.

  (Measured Max. Density)(Barrel to be Crushed Vol.) = Max. Barrel Wt.

$$\frac{\text{(Expected Lbs.)}}{\text{(In. of Crushed Ht.)}} = \frac{\text{(Vol. Reduction Desired)[(Optimum Beginning Density)(Crushed Bl. Vol.) + (Crushed Bl. Tare Wt.)]}}{\text{(Inches of Crushed Barrel Height)}}$$

- o Calculate Actual Plant Volume Reduction Expected at the Burial Site:

$$\text{Average Crushed Barrel Ht.} = \frac{\text{(Actual Average Plant Barrel Wt. To Be Crushed)}}{\text{(Expected Pounds Per Inch of Barrel Height)}}$$

$$\text{Fractional Number of Drums/Overpack} = \frac{\text{(Inside Overpack Height)}}{\text{(Avg. Crushed Barrel Ht.)}}$$

$$\text{(Actual Plant Vol. Red.)} = \text{(Fractional No. of Drums/Overpack) (.94)}$$

Note: (This is the adjustment factor from Table III, and will change depending on the waste type to be crushed).

With a sorting program implemented, the adjustment factor from Table III will tend to be constant for all waste types because the sorting program should yield a consistent packaging efficiency within the overpack.

Conclusions In Calculating Volume Reduction from Supercompaction

Volume Reduction can be best defined by using beginning and ending densities. As such, the people involved should make a realistic effort to accurately estimate their beginning density and type of waste being compacted. By using the adjustment factors from Table III, and the above calculation method for determining estimated burial volume, an accurate prediction can then be made of what volume reduction to expect at the burial site.

Volume reduction can be more cost effective by taking the following steps:

- o Use 52-gallon drums as the drum to be crushed with 55-gallon drums as overpacks.
- o Insure that the supplier of the supercompaction service defines the maximum barrel weight to achieve the expected volume reduction, and that it not be exceeded.

Remember that no supercompaction service can achieve any greater than the theoretical density of the material being crushed. The one exception is a porous material that naturally occurs as porous, i.e., wood, where better than theoretical densities are achieved with this type of material because the voids are eliminated. Areas such as this are where experienced has proven valuable in determining what can be achieved in volume reduction via supercompaction.

Supercompaction has proven to be a cost-effective means of achieving a 2:1 or greater volume reduction with DAW as well as non-compactables such as brick, steel, concrete rubble, tile rubble, pipe, soil, and wood. The volume reduction the waste generator will achieve will be no greater than the ratio between begining and final density, and will probably be somewhat less due to packaging inefficiencies.