USE OF TIRE CHIPS IN LANDFILL GAS EXTRACTION APPLICATIONS

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ABSTRACT
One of the significant costs in the construction of a landfill gas collection system is the aggregate materials used in vertical extraction wells and horizontal collectors. In geographic areas of the country where non-calcareous stone is expensive, such as Florida, tire chips can be a cost-effective alternative permeable backfill material for landfill gas-related construction. While the use of tire chips in the drainage layers of leachate collection and removal systems (LCRS) is becoming more common, only recently has there been increased interest in using tire chips for passive landfill gas vent systems and vertical extraction wells. This application of tire chips also represents a positive use for waste tires as part of integrated solid waste management programs.

This paper discusses the engineering, permitting, construction, and operational aspects of using tire chips in landfill gas vents, wells, and horizontal collectors. Performance and cost comparisons between tire chips and non-calcareous rock and potential permitting issues associated with using tire chips in landfill gas systems are presented. Typical specifications and guidance on how to address design considerations for tire chips, including compression, pore space, and soil intrusion are discussed.

Six case studies are presented for landfills throughout Florida and the Southeast United States where tire chips have been used successfully in landfill gas management projects. These projects were constructed from 2000 through 2005 and are currently in operation.

SCRAP TIRE BACKGROUND INFORMATION
The Rubber Manufacturers Association (RMA) estimates that approximately 290 million scrap tires were generated in 2003, which is the last year for which data have been compiled. Of this, approximately 233 million tires were directed to end-use markets. The largest market for scrap tires is for tire-derived fuel, which accounts for approximately 45 percent of scrap tire utilization. The second most popular end-use market is in civil engineering applications, which consumed over 56 million scrap tires in 2003, or 19 percent of the market for scrap tires. The third highest use of scrap tires is for ground rubber for new products, playground and sports surfacing, and rubber-modified asphalt. Even with the emergence of markets for scrap tires, the RMA estimates that 275 million scrap tires remain in stockpiles in the U.S. (RMA, 2004).

<u>State Regulations and Programs</u>
Thirty seven states ban the burial of whole tires in landfills. In an effort to provide a market for the reuse of scrap tires and to decrease the number of scrap tire stockpiles, 32 states provide grants or loans to the processors and recyclers of scrap tires. Typically, these programs are funded, at least in part, by a fee that is collected at the time of sale of new tires.

For example, in Florida, grants are made available to County governments to purchase products that are made from tires. In addition, the Florida Department of Transportation (DOT) specifies that rubber-modified asphalt must be used for all road surfacing projects. In Louisiana, using a portion of the $2 collected for each new tire sold by retailers, the State pays a stipend to tire processors equal to $1.50 for every 20 pounds of scrap tires that are used for a beneficial end use. In Oklahoma, riverbank stabilization projects are eligible for State reimbursement of $1.50 per truck tire when the tires are obtained from priority dump sites. In part because of such programs, the RMA (2004) estimates that 34 states have end use markets that are sufficient to handle the annual generation of scrap tires.

<u>Non-Landfill Civil Engineering End Uses</u>
Over the past decade, the use of tire chips has been increasing in a number of civil engineering applications such as in road embankment construction, river bank restoration, and in asphalt repaving. For road and bridge construction, the lightweight, low-pressure, and free-draining nature of tire chips are significant benefits when used as a backfill material.

The U.S. EPA reports that asphalt rubber is the largest single market for ground rubber. In this application, scrap tire rubber is used in the asphalt rubber binder, seal coat, cap seal spray, or as an aggregate substitute (i.e., rubber modified asphalt concrete). This combination of uses accounts for approximately 220 million pounds of ground scrap rubber. California, Arizona, and Florida are the three leading states for rubberized asphalt usage.

States such as Alabama, Florida, Georgia, South Carolina, and Virginia also permit the use of tire chips in septic tank leach beds.

Tire Chip Applications at Landfills
In landfills, tire chips have been used as alternative daily cover, in leachate recirculation trenches, as selective fill above the leachate collection and removal system (LCRS) in new cells (i.e., the operations layer), and as a primary drainage component in the LCRS. In Florida, the use of tire chips as a substantial component of the LCRS has been demonstrated by the Hillsborough County (Florida) Solid Waste Management Department where tire chips are used in the drainage layer of new cells at the Southeast County Landfill. In the late 1990s, Waste Management Inc. of Florida used tire chips in augmenting an older bottom liner design to enhance leachate removal prior to initial filling. That system included supplemental tire chip trenches with a geotextile buffer layer installed between the tire chips and the geomembrane liner.

Uses for Tire Chips in Landfill Gas Systems
Historically, tire chips have been used in landfill gas applications as the permeable backfill material in venting layers below the landfill cap and in passive vent trenches outside the limit of waste. In recent years, there has been a significant increase in the use of tire chips for constructing horizontal landfill gas collectors. And in more limited cases, tire chips have been used in lieu of rock backfill in vertical landfill gas extraction wells and passive vents.

PHYSICAL PROPERTIES
Significant literature has been published that provides the physical properties of tire chips, which are summarized below.

- **Density** – The loose density of tire chips ranges from 20 to 30 pounds per cubic foot (pcf). In-place compacted densities of tire chips range from 30 pcf for thin layers with no soil cover to approximately 60 pcf for thick lifts with thick soil cover. This shows that the unit weight of tire chips increases under the weight of overlying soils and tire chips (Texas DOT, 2004). It should also be noted that as the tire chip size increases, the unit weight decreases as the pore space also increases. As a comparison, in-place gravel weighs approximately 125 pcf.

- **Specific Gravity** – Ranges of specific gravity from 1.02 to 1.27 have been reported, depending on the amount of steel wire in the tires. This means that the tire shreds or chips are heavier than water and will sink. The specific gravity of soils is generally more than double that of tire chips, or between 2.60 and 2.80 (Texas DOT, 2004).

- **Compressibility** – When designing any application that utilizes tire chips, compressibility is one of the most important properties to consider. As a practical point, tire chips differ from soils in that while the mass of both materials will compress during installation, each individual tire chip also compresses. Vertical strains of up to 25 percent have been reported for 3-inch tire chips under vertical stresses as low as 7 pounds per square inch (psi). Vertical strains of up to 40 percent have been reported under vertical stresses of 60 psi.

- **Hydraulic Conductivity** – As vertical loading increases and the tire chip layers compress, thereby reducing void space, the hydraulic conductivity of the tire chip backfill decreases. A detailed comparison of reported hydraulic conductivity for various tire chip sizes was prepared by Reddy and Marella (2001). Various tests indicate that the hydraulic conductivity of tire chip sizes typical of landfill gas applications (i.e., greater than 2 inches) ranges from a minimum of 0.5 cm/sec to over 20 cm/sec. Texas DOT (2004) reports tire chip permeability greater than 10 cm/sec.

  The lower end of the reported range is representative of smaller chips and/or higher applied loads (i.e., over 5,000 psf, which corresponds to the pressure exerted by over 80 feet of waste on top of the chips). It has been reported that the pore space provided by the tire chips allows approximately 100 percent more gas transmission than traditional aggregate (Nebraska State Recycling Association) and promotes condensate or leachate drainage on the order of 10 times higher than well-graded soils (RMA, 2004).

- **Shear Strength** – A range of values for shear strength (φ = 24 to 38 degrees) have been reported depending on the chip size, amount of protruding wire, and degree of saturation (Dempsey et al. (1996)). The Young's modulus of tire chips is approximately 2 to 3 orders of magnitude less than the modulus of granular soil. This property typically has little value with respect to landfill gas systems.

- **Flammability** – Tires are flammable and exothermic reactions in tire chip fills have been documented. However, as reported by the Texas DOT, of the 70 installations of tire chip backfill for road construction projects documented by 2004, only three experienced exothermic, or heat producing, reactions. These projects in Washington and Oregon were both over 50 feet deep and contained a mix of soil and tire chips, which resulted in a fill material that was less compressible than tire chips alone. They also included tire chips that contained significant amounts of exposed steel and were contaminated with liquid petroleum. The authors are aware of no landfill fires that have been directly or indirectly affected by, or attributed to, the presence of tire chip backfill within a landfill.

DESIGN CONSIDERATIONS

When designing landfill gas collection systems that use tire chips as a backfill material, the most important considerations are tire chip size, permeability, compaction, and compressibility. However, the most controversial properties typically are flammability and compressibility.

Tire Chip Size

The authors typically specify 3-inch nominal size tire chips, with a gradation similar to an AASHTO No. 3 stone. This tire chip size is generally available from suppliers, is appropriate for use with typical slotted and perforated pipe designs, and has been used successfully in horizontal gas collectors and vertical landfill gas extraction wells.

As with aggregate and other coarse backfill, specifications for tire chips should include a limit on the acceptable quantity of oversized or fine material that can be present. Without a specification for tire chip size and adequate construction quality assurance inspection, excessive settlement may occur or the effectiveness of the collector can be compromised.

Permeability

The hydraulic conductivity of 3-inch tire chips is comparable to that of typical drainage materials, and except under the most extreme compressive forces, tire chips provide the same, if not better, conductivity as compared to aggregate. The authors have not witnessed any situations where the permeability of 3-inch nominal size tire chips used as backfill in landfill gas collectors or wells appeared to be less than that of stone.

Compaction and Settlement

In order to minimize post-construction settlement, tire chip backfill must be properly compacted in order to minimize excess void space. The Texas DOT (2004) reports that settlement of 3-inch tire chips is less than the settlement of 12-inch chips. If the tire chip backfill is not adequately compacted, over time and/or with the application of vertical loads in the future, the tire chips will settle into these voids and result in localized ground settlement. The presence of excess voids around the walls of the collection pipe also diminishes the pipe strength.

For horizontal collectors, compaction can be accomplished by using an excavator bucket to press down onto the installed tire chips or by driving over the trench with track-mounted equipment. Settlement caused by inadequate compaction typically is not evident once waste has been filled on top of the collectors.

However, with vertical extraction wells, localized settlement can be significant. In the case of vertical wells installed with tire chip backfill at a landfill in Delaware, settlement ranging from 5 to 10 feet was reported around well casings. While the cause of this settlement was not fully known, the contractor suspects that large tire shreds caused “bridging” and the formation of voids within the tire chip backfill. Once soil backfill was placed above the tire chip layer, these voids collapsed, and the ground surface subsided. Unless the tire chip backfill extends a substantial distance above the top of the slotted collection pipe, such settlement can result in soil infiltrating the well casing and reducing the effectiveness of the well.

Compressibility

While proper backfilling techniques can minimize some of the settlement of tire chip layers, designers should consider compressibility when designing horizontal collectors and vertical extraction wells with tire chip backfill. For horizontal collectors, it is prudent to increase the thickness of the permeable backfill layer in accordance with the expected overlying pressures. Assuming a compression of 30 percent, if the desired trench thickness is 3 feet deep, the trench depth at the time of construction may need to be increased to 4 feet in order to account for settlement and compression.

For vertical extraction wells, a similar approach should be used such that the resultant settlement due to compression yields a tire chip backfill that extends above the top of the perforated or slotted well casing. While backfilling of horizontal trenches enables compaction with standard equipment, when backfilling a borehole, compaction is normally accomplished only via the weight of the tire chips and the fill dirt. The expected compression of the tire chip backfill can be estimated based on empirical and laboratory data presented in various literature referenced at the end of this paper.

At the Orange County (Florida) Solid Waste Management Facility, SCS Engineers (SCS) designed 10 vertical extraction wells with tire chip backfill extending 1 foot above the top of the slotted well casing. After four years in operation, field personnel report no settlement at the well casings, which indicates that the tire chips have not compressed significantly.

A recently installed landfill gas system in Hillsborough County (Florida) was designed by SCS to include 10 vertical wells with a minimum of 5 feet of tire chip backfill extending above the top of the slotted well casing. Three months after installation, there are no signs of localized settlement that would indicate significant settlement of the tire chips.

ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS

The choice to use tire chips as a permeable backfill material may be based on either economics and/or the desire to provide a beneficial end use for scrap tires.

Economic Feasibility

The economic feasibility of using tire chips in lieu of coarse aggregate as a construction material for landfill gas collectors and wells depends on the availability of both materials. In terms of economics, the cost of tire chips is driven by the market for the chips. Where there is a source of tire chips and/or a market for their use, costs can be comparable to rock, which is the case in Florida and Louisiana. Based on recent material quotes in Florida, tire chips are approximately $41 per cubic yard (not including delivery), compared to non-calcareous rock costs of $46 per cubic yard for AASHTO No. 3 stone and over $60 per cubic yard for No. 4 stone. Note that these costs have been converted from a cost per ton to cost per cubic yard basis to account for the differences in density of the materials.

In states where rock is relatively inexpensive (e.g., Georgia), tire chip use is not common, processors are not plentiful, or the burial of tires in landfills is permitted (e.g., Alabama), tire chip costs are generally higher than for No. 3 or No. 4 rock. For example, typical rock prices in Georgia (not including delivery) range from $18 to $20 per cubic yard, which is approximately one half the $35 per cubic yard cost of tire chips. In Alabama, the cost of rock is less than $10 per cubic yard and tire chips are not available. In Louisiana, the cost of 4-inch tire chips is the same as for No. 3 rock.

In circumstances in which a landfill owner processes tires on site, tire chip costs may be essentially zero and the economics strongly favor tire chips over rock. Similarly, at a site in Louisiana, the tire processor provided the tire chips for free. This example illustrates that landfill owners may find significant cost savings by investigating the availability of tire chips, especially if a tire processor is located in close proximity to the site, or is currently paying a tipping fee to dispose of tires.

Environmental Incentives

As part of an integrated solid waste management program, using tire chips as a backfill material can be seen as environmentally beneficial, which may be important to some landfill owners.

REGULATORY CONSIDERATIONS

There appears to be little reluctance from regulators in the Southeastern U.S. and California regarding the use of tire chips in landfill gas collection systems. In Florida, the Central, Southwest, and South districts of the Department of Environmental Protection (FDEP) have approved landfill gas collectors and wells that use tire chip backfill. In Mississippi, the Department of Environmental Quality (MDEQ) has published literature that encourages the use of tire chips in landfills. Louisiana Department of Environmental Quality (LDEQ) recently approved a series of horizontal collectors at an active landfill in the southern part of the state. Staff from the Alabama Department of Environmental Management (ADEM) and Georgia Environmental Protection Division (GA EPD) have stated that using tire chips in landfill gas systems would be no different than standard construction methods from a permitting perspective.

The waste tire program funded by the State of Louisiana offers an economic incentive for using tire chips in environmental projects. Therefore, LDEQ requires the permittee to quantify the volume of chipped tires that will be used in the project. Once the project is completed, the State of Louisiana pays the tire processor $150 per ton of tire chips that are reused in beneficial use projects.

Also, in its 1998 Guidance Manual on the Use of Tire Shreds as Gas Collection Material at MSW Landfills, the California Integrated Waste Management Board stated that "there are no restrictions of the use of tire shreds as LFG collection material for collection trenches within the waste mass or as vertical well backfill."

CASE STUDIES

Provided below are case studies in which tire chips were used in constructing landfill gas collectors and wells in the Southeast U.S.

Horizontal Collectors

In addition to the 10 vertical wells installed at the Orange County (Florida) Solid Waste Management Facility that are described below, Orange County installed 3 horizontal collectors in the Class III landfill and 19 horizontal collectors in the municipal solid waste (MSW) landfill. The three collectors in the Class III landfill were a combined 1,500 feet long. The horizontal collectors in the MSW landfill total approximately 24,200 feet in length. Horizontal collectors were chosen for these active landfill areas in order to accommodate waste filling operations.

The collectors installed by Orange County consist of a perforated 6-inch diameter HDPE collector pipe centered in a 3-feet by 3-feet geotextile-wrapped trench that was backfilled with 3-inch tire chips, and vary in depth from 20 feet to over 120 feet below ground surface. In the MSW landfill cell, the horizontal collectors account for over half of the landfill gas collected from this part of the site. Each collector in the MSW landfill cell has a 3-inch Landtec wellhead to accommodate the high gas flow rates. By using tire chips, Orange County reduced construction cost for the horizontal collectors by over $20,000.

Horizontal collectors with tire chip backfill have been designed and installed by SCS at three additional landfills in southern Florida and Louisiana. In southern Florida, these installations total 10,000 feet of tire chip-backfilled horizontal collectors. Eleven of the collectors that were installed in 2001 are now under approximately 70 feet of waste and are still in operation today. Construction cost savings exceeded $10,000 for these 11 horizontal collectors.

At a landfill in Louisiana, eight collectors totaling approximately 4,000 feet were installed in 2005. These collectors were installed in an active area of the site in order to proactively control landfill gas odors and surface emissions. The collectors are in an area of the landfill that experiences significant settlement, but are functioning as designed. Gas quality is affected by fluctuating liquid levels in the collectors, but there are no signs that there are any problems associated with using tire chips in lieu of stone backfill. In this instance, the tire processor provided the tire chips at no cost, which saved the landfill owner approximately $60,000.

Shallow "Surface" Collectors

Waste Management Inc. of Florida has used tire chip backfill to construct 14 shallow wells, or "surface collectors", that serve as temporary odor control wells. These collectors were constructed in 2005 by excavating 15-feet deep pits, installing collection piping, and backfilling around the perforated pipe section with an 11-foot thick layer of tire chips. The remaining portion of the excavation was backfilled with clean soil.

Orange County (Florida) installed two surface collectors in 2001 to augment landfill gas collection from a portion of a closed MSW landfill cell. These wells were drilled to depths of approximately 35 feet and were constructed of slotted pipe and tire chip backfill extending to the ground surface. A geomembrane cap is installed in this area of the landfill.

Vertical Extraction Wells

The authors have designed vertical extraction wells with tire chips at two closed landfills in Florida. Tire chips are not commonly used in constructing vertical extraction wells due to the potential for settlement of the tire chips around the well casing and concerns about the effects of differential settlement of the waste. As addressed in the previous discussions, the factors attributed to settlement can be overcome by adding proper design and installation procedures.

Orange County, Florida: Ten vertical wells with tire chip backfill were installed at the Orange County Solid Waste Management Facility in an area known as the Pre-1985 Landfill, which was closed with a soil cap prior to 1985. Each of these wells are approximately 25 feet deep and consist of 10 feet of slotted pipe and 15 feet of solid-wall pipe below ground surface. The tire chip backfill extended 1 foot above the top of the slotted well casing. A geotextile donut was installed above the tire chips prior to backfilling with 1 foot of soil, followed by a 2-foot thick bentonite plug. Because these wells are relatively short, the construction costs were reduced by a modest $1,300 for this project by using tire chips.

As stated above, no significant settlement has been witnessed and there have been no instances of elevated well temperature in these wells. The wells have marginal gas quality, which is due to the relatively old waste in place and, in some instances, high liquid levels in the wells. Video inspection of the wells shows no significant biological growth or any soil infiltration, even though the construction included only 1 foot of tire chips above the top of the slotted well casing. This indicates that there has been no settlement of the tire chips.

Hillsborough County, Florida: In Hillsborough County, 10 of the 72 new vertical extraction wells for a landfill gas system renovation project at a closed landfill were installed with tire chips. These wells varied from 22 to 70 feet deep, and totaled 460 feet of drilling, with 337 feet of tire chip backfill. The wells were installed in 36-inch boreholes, with tire chip backfill extending 5 feet above the top of the slotted well casing. A bi-planar geocomposite donut was installed above the tire chip backfill to prevent the infiltration of soil into the tire chips. The geocomposite will also serve to distribute the normal force of the backfill material onto the tire chips. Soil backfill was placed above the geocomposite, followed by a 2-foot thick bentonite plug. Because the County processes tires at another of its facilities, the tire chips used for backfilling these 10 wells were free. This decreased construction costs by over $16,000.

In order to allow future inspection of the tire chip backfill, a 4-inch diameter observation pipe was installed in the borehole adjacent to the well casing. The observation pipe is open at the bottom to facilitate future video inspection and sample collection. The tire chip-backfilled wells were also inspected using a down-hole camera within one month of coming on-line in order to provide a baseline for comparing future conditions in the wells.

Since bringing these wells on line, the performance of the wells has been consistent with the other wells on site.

<u>Limitations</u>

It should be noted that the two case studies presented above for vertical extraction wells are for wells that were installed in landfills that have been closed for over 15 years. Wells in active or recently closed landfills will likely experience significantly more differential settlement of the waste than in older closed landfills such as these, which would impact the integrity of the wells.

CONCLUSIONS

Utilization of tire chips in landfill gas applications is becoming more common where there is an economic or environmental incentive to do so. In summary:

- Tire chips have hydraulic and gas conductivity values comparable to or higher than coarse aggregate, which makes them acceptable for use in landfill gas collection systems.
- Successful projects have use 3-inch tire chips with a gradation similar to AASHTO No. 3 stone.
- Compressibility of the tire chips must be considered in designing the backfill thickness.
- For vertical extraction wells, the tire chip backfill should extend a minimum of 5 feet above the top of the slotted pipe. A greater thickness is warranted for higher expected compression rates.
- Construction CQA inspectors should ensure proper backfilling and compaction methods are used to minimize “bridging” of the tire chips and avoid excessive future settlement.
- Tire chip backfill has been used successfully in horizontal collectors throughout Florida in landfills that generate a substantial amount of landfill gas. In some cases, these collectors are buried under more than 100 feet of waste and are still functioning properly.
- The use of tire chips for backfilling vertical wells has not been well documented.

However, recent installation of vertical wells with tire chip backfill, we hope to demonstrate the feasibility of using tire chips as an alternative backfill for vertical well installation under certain circumstances. Future study will include video inspection of installed wells and sample collection from observation pipes in order to document situations such as the occurrence of in-situ biological growth on tire chips or degradation of the chips.

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