Evaluation of Rockford Sand & Gravel Co. Lime By-Product

By Tarun R. Naik and Rudolph N. Kraus

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Department of Civil Engineering and Mechanics
College of Engineering and Applied Science
THE UNIVERSITY OF WISCONSIN - MILWAUKEE
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A Report Submitted to Mr. Dale Wieman
Rockford Sand and Gravel, Inc.
Loves Park, IL

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Executive Summary

TITLE: Evaluation of Rockford Sand & Gravel Co. Lime By-Product


BACKGROUND/PURPOSE: To conduct physical, chemical, mineralogical, and microstructural tests for determining properties of lime by-product, provided by Rockford Sand and Gravel Co., for evaluating its potential options for beneficial reuse.

OBJECTIVE: The primary objective of this project was to recommend alternatives to the normal practice of land filling by evaluating potential reuse/recycle applications for this material.

CONCLUSIONS: The Rockford Sand and Gravel (RS&G) Co. lime by-product has potential for many applications. The actual performance needs to be established for individual applications. The following are some of the potential high-volume applications. A very important application could be supplemental mineral addition to coal, and spraying coal to minimize dusting due to coal handling, transportation, and storage using the RSG lime by-product at a higher water content level. The lime by-product could also be used in clean-coal applications for the removal of sulfur dioxide emissions from flue gas. Since the RSG lime by-product is primarily composed of calcium carbonate, another important application may be in paper production where it can be used as a filler for different types of paper. This material may be useful for replacement of clay in clay bricks manufacturing, with or without the use of fly ash. Soil stabilization or site remediation is another significant potential use for this material. For example, for storage-yard paving (with or without asphaltic or roller-compacted concrete pavement) this lime by-product with fly ash can function as a soil stabilizing or strengthening medium as well as significantly improving the performance of pavements, and reducing handling cost of stored materials. Of course, roller-compacted asphalt or concrete pavements can be used for many other applications also (e.g., parking lots, industrial floors, roadways, highways, airfield pavements, etc.). The test data collected indicates that this material can also be used in flowable slurry with or without crushed limestone fine sand.

RECOMMENDATIONS: There is a significant value available from this lime by-product. Further evaluation is strongly recommended, starting with lab-scale production and testing of products for above applications. Cost/benefit analysis and marketing studies should be undertaken; and a long-term evaluation program for these products should be immediately started. This includes the development of lime by-product specifications for high-potential, high-value, applications. A quality control program, process, and specifications would have to be established before the lime by-product is sold to third party users.
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Section 1

INTRODUCTION

The scope of this project was to determine physical, chemical, mineralogical, and microscopical properties of a material from the Rockford Sand and Gravel (RS&G) Co. This material is a lime by-product obtained from the City of Aurora, Illinois. The main objective of this project was to recommend alternatives to the normal practice of land filling by recommending potential recycling applications for this material.

It has been established from other activities at the UWM Center for By-Products Utilization (UWM-CBU) that properties of similar by-products can vary depending upon many unique situations under which a by-product is produced and collected. Therefore, it is important to determine physical, chemical, and morphological properties of the by-product when determining its appropriate use options.

The lime by-product evaluated for this project is a by-product of the clarifier and softener from the water purification plant of the City of Aurora, Illinois. Lime is added to increase the pH, to precipitate particles causing turbidity, iron, manganese, and radioisotopes, to improve water clarity and reduce hardness by approximately 70% [1].

The hardness of water is caused by the presence of calcium and magnesium salts in solution form. The hardness is primarily associated with bicarbonate and sulfate ions. The softening process consists of removing a part of the calcium and magnesium from the water. The primary precipitate that forms as a result of the chemical softening process is calcium carbonate. The amount of magnesium hydroxide formed is determined by the amount of magnesium contained
in the “raw” water. The chemistry of water softening is given by the following chemical
reactions that occur when lime is added to water containing calcium and magnesium salts [2]:

\[
\begin{align*}
\text{CaO} + \text{H}_2\text{O} &= \text{Ca(OH)}_2 & (1) \\
\text{CO}_2 + \text{Ca(OH)}_2 &= \text{CaCO}_3 \downarrow + \text{H}_2\text{O} & (2) \\
\text{Ca(HCO}_3)_2 + \text{Ca(OH)}_2 &= 2\text{CaCO}_3 \downarrow + 2\text{H}_2\text{O} & (3) \\
\text{Mg(HCO}_3)_2 + \text{Ca(OH)}_2 &= \text{CaCO}_3 \downarrow + \text{MgCO}_3 + 2\text{H}_2\text{O} & (4) \\
\text{MgCO}_3 + \text{Ca(OH)}_2 &= \text{CaCO}_3 \downarrow + \text{Mg(OH)}_2 & (5) \\
2\text{NaHCO}_3 + \text{Ca(OH)}_2 &= \text{CaCO}_3 \downarrow + \text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O} & (6) \\
\text{MgSO}_4 + \text{Ca(OH)}_2 &= \text{Mg(OH)}_2 \downarrow + \text{CaSO}_4 & (7) \\
\text{CaSO}_4 + \text{Na}_2\text{CO}_3 &= \text{CaCO}_3 \downarrow + \text{NaSO}_4 & (8)
\end{align*}
\]

Equation 1 shows the reaction when lime is slaked prior to adding to the water. Equation 2
represents the reaction of the calcium hydroxide with remaining dissolved carbon dioxide that
may remain in the water after the aeration process. The dissolved carbon dioxide must be
accounted for in order to adequately balance the hardness of the water. Equation 6 shows a
reaction with sodium bicarbonate, which is part of the alkalinity of the water and will also react
with a portion of the calcium hydroxide. Equations 3, 4 and 5 show the removal of carbonate
hardness by lime. Equation 7 shows the removal of magnesium sulfate by lime. This reaction
does not affect the hardness of the water as an equivalent amount of calcium sulfate (non-carbon
hardness) is produced. Finally, as shown in Equation 8, the calcium sulfate reacts with sodium
carbonate. The amount of lime that is required for these chemical processes are calculated based
on the amount of free carbon dioxide, bicarbonate, alkalinity, magnesium hardness, and non-
carbonate hardness of the water.
Lime softening is also very effective in removing up to 99% of the radioisotopes radium and uranium. These naturally occurring radioactive materials are concentrated in the by-product materials that precipitate from the clarifier. The lime by-products are generally treated as non-radioactive and are disposed by traditional methods [3].
Section 2

Tests of Rockford Sand and Gravel Co. Lime By-Product

EXPERIMENTAL PROGRAM

A test program was designed to measure physical, chemical, mineralogical, and microscopical properties of the lime by-product. These properties are necessary before determining possible uses of the lime by-product, and recommending specific laboratory studies to develop potential applications. In order to determine the properties of the lime by-product material, the following experiments were carried out.

PHYSICAL PROPERTIES

Physical Appearance

Before beginning any quantitative testing, the general physical appearance of the material was evaluated. The as-received condition of the RS&G lime by-product is a high moisture content material, with a very fine particle size. The consistency of the material is similar to a soft clay. When dried, the RS&G lime by-product material is light gray in color and dries into a brittle, highly consolidated material. When crushed after drying, it is similar to a coal fly ash with a very fine particle size.

As-Received Moisture Content

As-received moisture content (MC) of the lime by-product was determined in accordance with ASTM Standard C 311. Table 1 provides the test data. The results show that the RS&G lime by-product has a very high moisture content, 92 percent. The high moisture content of the lime by-product may impact the potential usefulness of the material, especially since many of the high
and medium technology applications that may be applicable for the lime by-product material requires a low moisture content. The high moisture content of the material would also increase shipping costs, particularly for end users who would require a dry product for their use. Wet lime by-product, on the other hand, may be useful as a mineral additive to coal prior to its burning and for dust control when handling, shipping, storing, etc.

**Particle Size Analysis**

Lime by-product samples were oven-dried at 210°F ± 10°F and then were tested for gradation. The lime by-product was not evaluated using ASTM C 136 and C 117 because the material was too fine to conduct these tests meaningfully. The lime by-product was tested for materials passing No. 325 sieve by washing under pressure in accordance with ASTM Test Designation C 430. Results are reported in Table 2. Only 19% of material tested was coarser than No. 325 sieve. The particle size distribution of the lime by-product was also analyzed in accordance with a modified ASTM C 422 test procedure (hydrometer analysis). Appendix 1 provides the details of this modified ASTM test. The complete size distribution for this material is shown in Fig. 1. This figure shows that the gradation of the lime by-product is reasonably uniform. The particle size distribution of the lime by-product is slightly finer than typical coal fly ash. The mean particle diameter for the lime by-product is about 33 microns.

Table 2 data show that the lime by-product is very fine, as indicated by the small amount of material retained on the No. 325 sieve (19%). ASTM C 618 for natural volcanic ash and coal fly ash classifies a maximum value of 34% retained on the No. 325 sieve as satisfactory for use of ash in concrete. Based upon the criteria for natural volcanic ash and pulverized coal fly ash, the lime by-product met this requirement of ASTM C 618.
Unit Weight

Unit weight (i.e., bulk density) of the lime by-product was determined in accordance with the ASTM Test Designation C 29. Table 3 provides the test results. The results show that the lime by-product had average density of 51.1 lb/ft³. This data indicates that the material may be suitable as a component for making lightweight concrete, as a partial replacement of sand. Such lightweight construction materials may be suited for structural-grade lightweight concrete slabs. It can also be used, along with an air-entraining agent, in a flowable condition as an insulating fill for roofs and walls, as well as sound and/or ground vibration barriers. Bulk density value is also necessary for calculations for establishing and modifying cement-based construction materials mixture proportioning. The percentage of voids values reported in Table 3 indicate amount of free space available for packing of other materials in making portland cement or asphaltic cement-based materials. The higher the percent voids, the higher the amount of other materials necessary for making such cement-based materials.

Specific Gravity

Specific gravity tests for the lime by-product material were conducted in accordance with the ASTM Test Designation C 188. Results show that the average specific gravity value of the lime by-product is 2.49, Table 4. This is a similar order of magnitude as a typical coal fly ash. Lime by-product has a specific gravity value similar to a typical Class F coal fly ash (specific gravity approximately 2.50), and lower than typical Class C fly ash (specific gravity approximately 2.60). Specific gravity value is necessary for determining relative substitution rate for the material versus amount of cement or sand replaced in a mixture; and, also for calculations for establishing and modifying cement-based construction materials mixture proportions.
ASTM C 618 TESTS

Physical Properties per ASTM C 618

ASTM C 618 provides standard specifications for volcanic ash and coal fly ash for use in concrete. Table 5 shows physical properties requirements for such ashes per ASTM Test C 618. There is no other similar test standard available for other types of pozzolonic materials. Therefore, to judge the suitability of the lime by-product for potential use as a mineral admixture in cement-based materials, physical tests were performed as described below in accordance with the ASTM Test Designation C 618. The following physical properties were determined: (1) Cement Activity Index; (2) Water Requirement.

Cement Activity Index

Cement activity index tests for the lime by-product were performed in accordance with the ASTM Test Designation C 311/C 109. Two-inch mortar cubes were made in a prescribed manner using a mixture of cement, sand, and water, without any lime by-product (Control Mixture). Compressive strength tests were conducted at the age of 3, 7, 14, and 28 days. Actual strength test results, in psi, are reported in Table 6 for the test specimens made from the Control Mixture. Additional test mixtures were prepared using 80% cement and 20% lime by-product material, by weight (instead of cement only without lime by-product as in the Control Mixture).

Comparison of the compressive strength of the lime by-product cubes, with the Control Mixture, is reported in Table 7. These results are designated as Strength Activity Index with Cement. In this comparison, the Control Mixture was assigned a value of 100, at each age, and all other compressive strength values were scaled from this reference datum.
The cube compressive strength test results, Table 6, for the lime by-product mixtures were lower than that for the Control Mixture without the lime by-product. The Activity Index with Cement data, Table 7, for this material was approximately between 67 to 70% up to the age of seven days for the lime by-product. It was slightly higher for the age of 14 and 28 days i.e. 72% which is lower than the 75% minimum required for coal ash by ASTM C 618 at the age of 28 days. The actual test data, Table 6, show that sufficient compressive strength can be achieved at all ages even though the lime by-product mixtures did not perform as well as the Control Mixture. Based upon the overall compressive strength data, it is concluded that the lime by-product is suitable for making structural-grade concrete. This material is satisfactory for housing construction where typically a compressive strength of 3,000 psi concrete, at the age of 28 days, is used. Typical concrete for roadways, highways, and airfield pavements has a competitive strength of 4,000 psi at the 28-day age. The lime by-product can be used for in-house concrete construction needs of the Rockford Sand and Gravel Co., as well as for general concrete construction.

In summary, ASTM C 618 classifies a value at 7-day or 28-day age of 75% or above for the Activity Index with Cement for coal fly ash as passing. Based upon this criterion, the lime by-product material does not pass the Strength Activity Index requirement. The lime by-product material also does not attain the 75% requirement at the age of 7-days (70.4%). Overall, the Activity Index with Cement test results of this material show that the lime by-product may be suitable for making structural-grade concrete in spite of slightly lower values for the strength activity index.
**Water Requirement**

Water requirement test for the lime by-product was performed in accordance with the ASTM Test Designation C 311. This test determines the relative amount of water that may be required for mixture proportioning of cement-based construction materials. It is well established that the lower the water required for a desired value of workability for the cement-based material, the higher the overall quality of the product. Test data for water requirement for the lime by-product are reported in Table 8. The results show that the average value for water requirement for the lime by-product material tested was lower than the maximum desirable value for water requirement. ASTM C 618 specifies a maximum value of 105 or 115, depending upon the type of ash, as an acceptable value for water requirement. For coal fly ash, the acceptable value is 105, while that for volcanic ash it is 115. It is, therefore, concluded that this lime by-product material may perform satisfactorily in cement-based construction materials.

**Evaluation with Activators**

The lime by-product material was evaluated with chemical activators to determine if the strength development characteristics of this material could be improved. Three different proprietary sources of activators were used for this evaluation: Activator #1, #2, and #3. Two different cement replacement rates (20% and 40%) were used to determine if improved compressive strength could be achieved using more lime by-product. Table 9 shows the actual strength test results at the age of 7 and 28 days. For comparison, the compressive strength results are shown for the standard 20% cement replacement rate without activators. The Strength Activity Index with Cement of the lime by-product mortar cubes, with and without chemical activators, is reported in Table 10. The Activity Index with Cement for the lime by-product without activators was 70.4% at the 7-day age and 72.3% at the 28-day age. ASTM C 618 specifies a minimum
compressive strength ratio of 75% for coal ash at either the 7-day or 28-day age. Without activators, the lime by-product did not meet the ASTM requirement at both the ages (i.e. 7 days and 28-days). The Activity Index results for the lime by-product with activators indicate that the use of Activators #1, at a 20% and 40% cement replacement reduces the compressive strength significantly at both the ages of 7 days or 28 days. Activators 2 and 3 also reduced the 7-day and 28-day strength when compared to the mixtures without the addition of activators. Based upon these results, it is concluded that activators tested do not improve the compressive strength of the cement mortar mixtures containing lime by-product and actually cause a reduction in the compressive strength.

**Chemical Properties per ASTM C 618**

Chemical analysis tests were conducted to determine oxides present in the lime by-product. X-ray fluorescence (XRF) technique was used to detect the presence of silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), iron oxide (Fe₂O₃), calcium oxide (CaO), magnesium oxide (MgO), titanium oxide (TiO₂), potassium oxide (K₂O), and sodium oxide (Na₂O). In this method, ignited samples were fused in a 4:1 ratio with lithium carbonate-lithium tetraborate flux and cast into pellets in platinum molds. The XRF technique for measuring sulfate (SO₃) involves grinding the lime by-product sample and manufacturing a compressed pellet with boric acid. A double dilution method using a 4:1 and a 10:1 ratio with boric acid was used to correct for matrix effects. These buttons were used to measure x-ray fluorescence intensities for the desired element, in accordance with standard practice for cementitious materials, by using an automated Philips PW1410 x-ray spectrometer. The percentages of each oxide were derived from the measured intensities through a standardized computer program based on a procedure outlined for low-dilution fusion. This is a “standard practice” for detecting oxides in cementitious
compounds, including portland cement, coal fly ash, and volcanic ash. Test results are reported in Table 11. Loss on ignition (LOI), moisture content, and available alkali (Na₂O equivalent) for the pre-dried lime by-product were also determined. These test results are also reported in Table 11.

According to the oxide analysis data, the lime by-product does meet Class N, C, or F coal fly ash requirements based on available alkali content. Maximum amount of available alkali for coal fly ash and volcanic ash is limited to 1.5% in accordance with the ASTM C 618. The available alkali content of the lime by-product is 0.04 percent, much less than the permitted limit. The calcium oxide content for the lime by-product is judged very good because the calcium oxide values are much above 10 percent. Furthermore, the magnesium oxide content of the lime by-product is judged to be low enough to minimize the soundness/durability related problems created due to a high MgO value (generally accepted to be greater than five percent). In general, all oxides present were within limits specified in the ASTM C 618 for coal fly ash and volcanic ash. The loss on ignition (LOI) value of this material is very high, 36.3%. The high-LOI value may be due to presence of organic material present in this by-product material. Further detailed investigation on the source of the LOI is required. The high-LOI value would be useful, however, if sufficient BTU value can be derived from it upon burning (for example, with coal).

In general, the lime by-product may be used for CLSM; however, additional evaluation of the LOI of the lime by-product is recommended before using it in structural-grade concrete.

**CHEMICAL COMPOSITION**

The mineral analysis, (i.e., chemical composition) for the Rockford Sand & Gravel Co. lime by-product material was conducted using the X-ray diffraction (XRD) method. The results are shown in Table 12. The lime by-product is composed almost entirely of calcite (CaCO₃).
ELEMENTAL ANALYSIS

The lime by-product sample was analyzed for total chemical composition by the Instrumental Neutron Activation Analysis (INAA). Knowledge of total elemental concentration is necessary because it provides an insight into the possibility of leaching potential characteristics of the material tested. Leaching of trace metals is known to be highly dependent upon how these trace elements are converted to chemical compounds. A high concentration of undesirable elements does not necessarily mean that these undesirable elements will leach. Tests for leachate characteristics, e.g. TCLP test, of a particular construction material must be performed in order to conduct the environmental assessment of the material proposed to be used and the product (e.g., cement-based material) to be made from it. The results for the elemental analysis performed on the lime by-product samples are reported in Table 13. The predominate elements (greater than 1000 ppm) found in the lime by-product material are aluminum, calcium, iron, and magnesium.

SCANNING ELECTRON MICROSCOPY (SEM)

A scanning electron microscope available at the University of Wisconsin-Milwaukee was employed for this part of the investigation. SEM pictures (photomicrographs) for the lime by-product were obtained, Figs. 2 through 5. These SEM pictures are an important part of understanding the character and morphology of the particles of the by-product being evaluated for considering their constructive use options. For example, studying the morphology allows judgment to be made regarding the physical and/or mechanical bond that might be possible for the product in creating new construction materials. In addition, it allows an opportunity to study the contours of the particles and how they may help in mixing and manufacturing these new
materials. The particle morphology helps in understanding the level of organic particles. This evaluation of organics and particle size distribution, also help in judging the water demand that may be placed upon for making cement-based materials.

The Rockford Sand and Gravel Co. lime by-product can be observed to be composed of heterogeneous mixture of particles of varying size. Unlike coal fly ash particles, the lime by-product particles are not spherical in shape. Therefore, due to irregular surface texture of particles, the addition of this material in cement concrete may increase the water demand for a given workability.
Section 3

Constructive Use Options for Rockford Sand and Gravel Co. Lime By-Product

INTRODUCTION

A number of uses of low-grade coal combustion products (CCP) in construction materials already exist [4]. However, these applications depend upon physical, chemical, mineralogical, and surface properties of such by-products. The same is true for the Rockford Sand and Gravel Co. lime by-product. The following sections deal with potential uses of the lime by-product analyzed in this investigation. As indicated by the mineralogical analysis, the Rockford Sand & Gravel lime by-product is nearly all calcium carbonate. Calcium carbonate has a number of uses that may be applicable to the Rockford Sand & Gravel By-Product. A list summarizing possible uses of the Rockford Sand and Gravel lime by-product is presented in Table 14.

FILLERS IN PLASTIC, RUBBER, CAULK, AND ROOFING SHINGLES

The Rockford Sand & Gravel lime by-product may also be useful as filler in the manufacture of plastics and rubber. Calcium carbonate can be used as a filler material in these industrial applications.

EXTENDERS IN PAINT APPLICATIONS

The Rockford Sand & Gravel Lime by-product also has potential as an extender in the manufacture of paint. Use of the Rockford Sand & Gravel lime by-product also has the potential to provide improved opacity of emulsion paints, easier dispersion, higher gloss, and may be able to replace a portion of the titanium oxide typically used in paint manufacture. Additional research should be performed to evaluate this use.
FILLERS IN PAPER MANUFACTURING

The pulp and paper industry uses calcium carbonate as a filler in its paper making process. The calcium carbonate is used as a replacement for the kaolin clay as a filler and coating pigments. Use of calcium carbonate as a filler in paper production has produced paper with a higher brightness, higher strength, more readily dried, and has increased paper production. When used as a coating pigment, calcium carbonate has similar advantages as when used in a filler application and provides an equivalent gloss to standard materials. Further investigation to this application is suggested. This could be a very effective use of this lime by-product.

SULFUR DIOXIDE REMOVAL IN COAL FIRED POWER PLANTS

Use of the Rockford Sand and Gravel lime by-product material may also be used for sulfur dioxide removal in coal fired power plants. The calcium carbonate component may be used in fluidized bed boilers to reduce sulfur emissions, or in lieu of limestone injection in other coal-fired boilers. This is also a very promising application for this lime by-product and should be investigated through additional testing.

CEMENT BASED USES

The size distribution of the lime by-product is similar to that of conventional coal ash products. In general, however, the lime by-product is finer than a typical coal fly ash. Furthermore, the material particles are irregular in shape versus spherical shape for coal fly ash. This means that when this lime product is added in mortar or concrete then the workability of fresh mortar or concrete may not be helped as much as that typical with the use of coal fly ash. In fact, some irregular particles shape may reduce the workability by increasing water demand of the mixture.
This investigation revealed that the lime by-product generally did not conform to all parts of the ASTM C 618 Class N, F, or C requirements for volcanic or coal fly ash for applications in cement-based composites. ASTM C 618 also gives standard specifications for natural pozzolans, Type N, which is volcanic ash. There are no ASTM standards available on lime by-product material use in cement-based materials. Therefore, the lime by-product cannot be directly compared to any ASTM standard specifications. However, the lime by-product is still expected to be suitable for use in concrete and other cement-based materials. The lime by-product is more suitable for CLSM and grouting applications due to its finer size.

In some applications in which conventional coal fly ashes are used, the lime by-product material probably cannot be used as a substitution of coal fly ash. However in combination with coal fly ash the lime by-product could be very effective. For more useful applications, further evaluation would be needed to develop optimum, high-volume use options.

**AGRICULTURAL APPLICATIONS AND ANIMAL FEED**

The lime by-product may also be used for agricultural applications. The carbonate content of the by-product would raise the pH of the soil necessary for optimum plant growth, and provide calcium as a soil amendment, increasing crop yields. Due to the content of several heavy metals in the by-product, this application should be evaluated for concentrations allowed by state and local agencies such as the Illinois EPA. Calcium is also required in many types of animal feed for milk cows, laying hens, or hogs. The concentration of metals in the lime by-product should also be evaluated prior to use for this application.
COAL BENEFICIATION AND DUST CONTROL AT POWER PLANTS

Coal storage piles at electric power plants require the addition of water to control dust. A slurry of the Rockford Sand and Gravel lime by-product material used for this purpose, would not only control dust, but provide additional source of lime when the coal is burned. The calcium carbonate component of the by-product, when subjected to high temperature would break down into lime and carbon dioxide. The additional lime component of the fly ash would increase the value of the fly ash produced when used in cement-based applications.
Section 4

Suggestions for Further Evaluations

As indicated in Section 3, the lime by-product has potential for many applications. However, the performance of the material needs to be proven for individual applications and for sale to users.

The following are some of the potential for applications that would require further proof for various uses. It is anticipated that these applications would consume most of the lime by-product produced by Rockford Sand and Gravel Co.

CLEAN-COAL TECHNOLOGY

Control of emissions from coal fired power plants, in a cost effective manner, is important to electric utilities. Use of the Rockford Sand and Gravel lime by-product material may be used for sulfur dioxide removal from these plants. The calcium carbonate component may be used in fluidized bed boilers to reduce sulfur emissions, or in lieu of limestone injection in other coal-fired boilers. Further study is very strongly recommended. Probability of success is very high.

COAL BENEFICIATION AND DUST CONTROL AT POWER PLANTS

Coal storage piles at electric power plants require the addition of water to control dust. If a slurry of the Rockford Sand and Gravel lime by-product material would be used for this purpose, it would not only control dust, but provide additional source of lime when the coal is burned. This additional lime would increase the value of the coal fly ash produced when used in cement-based applications such as wet-cast and dry-cast concrete. Further study is very strongly recommended. Probability of success is very high.
PAPER MANUFACTURING

The pulp and paper industry uses calcium carbonate as filler in its paper making process. The calcium carbonate would be used as a replacement for the kaolin clay as filler and coating pigments. Further investigation to this application is suggested. This would be a very effective use of the by-product, particularly since mills located in Wisconsin lead the U.S. in paper production. Probability of success is very high.

ROLLER-COMPACTED ASPHALT OR CONCRETE PAVEMENT

The lime by-product can be used for Roller-Compacted Asphalt or Concrete Pavement (RCCP) for improving the performance of pavements in all types of weather. Materials storage and handling yards pavement, using lime by-product, would be a very important application. RCCP popularity is increasing in the mid-west. Lab evaluation is very strongly recommended for future applications. Probability of success is very high.

FLOWABLE MATERIALS

Large amounts of lime by-product can be utilized in manufacture of flowable fill material. This is defined by ACI Committee 229 as Controlled Low-Strength Material (CLSM). The compressive strength of CLSM can be very little (10 psi) up to 1200 psi. This material can be used for foundations, bridge abutments, buildings, retaining walls, utility trenches, etc. as backfill; as embankments, grouts, abandoned tunnel and mine filling for stabilization of such cavities, etc. See Table 14 for more details.

CLSM can be manufactured with large amounts of lime by-product, low to zero amount of cement and/or lime, and high water-to-cementitious materials ratio to produce the flowable fill.
An evaluation study is very strongly recommended in order to produce CLSM for various applications with this material for approval by local environmental agencies, such as the Illinois EPA. Probability of success is very good.

**AGRICULTURAL APPLICATIONS AND ANIMAL FEED**

The lime by-product may also be used for agricultural applications. The carbonate content of the by-product would raise the pH of the soil necessary for optimum plant growth, and provide calcium as a soil amendment, increasing crop yields. Calcium is required in many types of animal feed for milk cows, laying hens, or hogs. Further study is recommended. Probability of success is very high.

**STRUCTURAL-GRADE CONCRETE**

The lime by-product can be used as a partial replacement of fines in concrete and mortar. This is one of the conclusions from the work conducted as a part of this test evaluation. Test results show that lime by-product did not meet the strength activity index requirement for ASTM C 618. However, the ASTM C 618 is written exclusively for coal fly ash (and natural/volcanic ash) materials. Future ASTM standards, therefore, may evolve which may apply to the lime by-product. In order to determine the effects of optimum inclusion of this lime by-product on concrete strength and durability properties, lab study is very strongly recommended. Probability of success is very high.

**BRICKS, BLOCKS, AND PAVING STONES**

The lime by-product has potential for applications in numerous masonry products such as bricks, blocks, and paving stones, especially with coal ash. Additionally, the lime by-product can be
utilized as a replacement of clay in manufacture of clay bricks. However, in order to meet the ASTM requirements for strength and durability, testing and evaluation work is necessary. The effects of the high-LOI content of the lime by-product must also be determined. The results of such testing would be used in developing specifications for the lime by-product in the manufacture of such masonry products. Evaluation is very strongly recommended. Probability of success is excellent to very high.

SOIL AMENDMENT WITH DREDGED MATERIALS

Illinois dredges a significant tonnage of dredged materials from the Great Lakes and rivers to keep the navigation channels open. The lime by-product would be an excellent additive to dredged materials to make manufactured topsoil for use in tree farms, sod farms, potting soil, pulp-mill new growth woods/plantations, etc. This material will act as a desiccant, deodorizer, and chemical activators for dredged materials. The resulting manufactured topsoil can be used as a fertilizer, and to decrease subsurface porosity and improve infiltration characteristics of soils. Further study is very strongly recommended. Probability of success is very high.
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

MOISTURE CONTENT
Table 1: As-Received Moisture Content of the RS&G Lime By-Product

<table>
<thead>
<tr>
<th>Source</th>
<th>Moisture Content, % (As-Received Sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual*</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>88.6</td>
</tr>
<tr>
<td></td>
<td>96.1</td>
</tr>
</tbody>
</table>

* Moisture Content, as-received, % = \(\frac{\text{as-received sample weight} - \text{dry sample weight}}{\text{dry sample weight}}\) x 100
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

PARTICLE SIZE ANALYSIS
Table 2: Materials Retained on No. 325 Sieve  
(Tests conducted per ASTM C 311/C 430)

<table>
<thead>
<tr>
<th>Source</th>
<th>% Retained on No. 325 Sieve (As-Received Sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>
Fig 1: Particle Size Distribution of Rockford Sand and Gravel Lime By-Product

ASTM D 422 Hydrometer Analysis
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

UNIT WEIGHT, VOIDS, AND SPECIFIC GRAVITY
Table 3: Unit Weight and Voids
(Tests conducted on as-received samples per modified ASTM C 29,
Utilizing 400 ml measure)

<table>
<thead>
<tr>
<th>Source</th>
<th>Unit Weight (lbs/ft$^3$)</th>
<th>Voids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Average</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>50.5</td>
<td>51.1</td>
</tr>
<tr>
<td></td>
<td>51.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Specific Gravity
(Tests Conducted per ASTM C 311/C 188)

<table>
<thead>
<tr>
<th>Source</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>2.48</td>
</tr>
</tbody>
</table>
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

ASTM C 618 PHYSICAL PROPERTIES
Table 5: Physical Test Requirements of Coal Fly Ash per ASTM C 618

<table>
<thead>
<tr>
<th>TEST</th>
<th>ASTM C 618 SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLASS N</td>
</tr>
<tr>
<td>Retained on No.325 sieve, (%)</td>
<td>34 max</td>
</tr>
<tr>
<td>Strength Activity Index with Cement at 7 or 28 days, (% of Control)</td>
<td>75 min</td>
</tr>
<tr>
<td>Water Requirement (% of Control)</td>
<td>115 max</td>
</tr>
<tr>
<td>Autoclave Expansion, (%)</td>
<td>±0.8</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>-</td>
</tr>
<tr>
<td>Variation from Mean, (%)</td>
<td>5 max</td>
</tr>
<tr>
<td>Fineness</td>
<td>5 max</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>5 max</td>
</tr>
</tbody>
</table>

Table 6: Mortar Cube Compressive Strength*  
(Tests conducted per ASTM C 311/C 109)

<table>
<thead>
<tr>
<th>Source</th>
<th>Compressive Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-Day</td>
</tr>
<tr>
<td>Control</td>
<td>3510</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>2310</td>
</tr>
</tbody>
</table>

*  ASTM C 311 is used in conjunction with ASTM C 618 for evaluation of strength development of mineral admixtures with portland cement. A mineral admixture is added as replacement of cement for the test mixture. Each result is an average of three compression tests.
Table 7: Strength Activity Index with Cement**
(Tested conducted per ASTM C 311/C 109)

<table>
<thead>
<tr>
<th>Source</th>
<th>3-day Test %</th>
<th>7-Day Test %</th>
<th>14-Day Test %</th>
<th>28-Day Test %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>67.2</td>
<td>70.4</td>
<td>72.2</td>
<td>72.3</td>
</tr>
</tbody>
</table>

** Results obtained from the mortar cube compressive strength results, Table 6.

Table 8: Water Requirement*
Tests conducted per ASTM C 311)

<table>
<thead>
<tr>
<th>Source</th>
<th>Water Requirement (% of Control)</th>
<th>ASTM C 618 Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class C</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>104</td>
<td>105 max</td>
</tr>
</tbody>
</table>

* Results obtained for the mortar cube mixtures.
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT
EVALUATION WITH ACTIVATORS
Table 9: Mortar Cube Compressive Strength with Activators*
(Tests conducted per ASTM C 311/C 109)

<table>
<thead>
<tr>
<th>Source</th>
<th>Activator</th>
<th>% Cement Replacement</th>
<th>Compressive Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>7-Day</td>
</tr>
<tr>
<td>Control</td>
<td>N/A</td>
<td>0</td>
<td>4425</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>None</td>
<td>20</td>
<td>3115</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>2350</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>1330</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>3045</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>1940</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>2620</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>1610</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>40</td>
<td>1610</td>
</tr>
</tbody>
</table>

* ASTM C 311 is used in conjunction with ASTM C 618 for evaluation of strength development of mineral admixtures with portland cement. A mineral admixture is added as replacement of cement for the test mixture. Each result is an average of three compression tests.
<table>
<thead>
<tr>
<th>Source</th>
<th>Activator</th>
<th>% Cement Replacement</th>
<th>Strength Activity Index (% of Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>7-Day</td>
</tr>
<tr>
<td>Control</td>
<td>N/A</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>RS&amp;G Lime By-Product</td>
<td>None</td>
<td>20</td>
<td>70.4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>53.1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>40</td>
<td>53.0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>40</td>
<td>43.8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
<td>59.2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>40</td>
<td>36.4</td>
</tr>
</tbody>
</table>

* Results obtained from the mortar cube compressive strength results, Table 9.
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

ASTM C 618 CHEMICAL PROPERTIES
Table 11: Chemical Analysis (oxides, LOI, moisture content, available alkali)
(Tests conducted on oven-dried samples)

<table>
<thead>
<tr>
<th>Analysis Parameter</th>
<th>ASTM C 618 Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RS&amp;G Lime By-Product</td>
</tr>
<tr>
<td>Silicon Dioxide, SiO₂</td>
<td>0</td>
</tr>
<tr>
<td>Aluminum Oxide, Al₂O₃</td>
<td>0.4</td>
</tr>
<tr>
<td>Iron Oxide, Fe₂O₃</td>
<td>0.4</td>
</tr>
<tr>
<td>SiO₂ Al₂O₃ + Fe₂O₃</td>
<td>0.8</td>
</tr>
<tr>
<td>Calcium Oxide, CaO</td>
<td>59.2</td>
</tr>
<tr>
<td>Magnesium Oxide, MgO</td>
<td>3.7</td>
</tr>
<tr>
<td>Titanium Oxide, TiO₂</td>
<td>0</td>
</tr>
<tr>
<td>Potassium Oxide, K₂O</td>
<td>0.04</td>
</tr>
<tr>
<td>Sodium Oxide, Na₂O</td>
<td>0</td>
</tr>
<tr>
<td>Sulfate, SO₃</td>
<td>0</td>
</tr>
<tr>
<td>Loss on Ignition, LOI (@ 750 C)</td>
<td>36.3</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>0.2</td>
</tr>
<tr>
<td>Available Alkali, Na₂O Equivalent (ASTM C-311)</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* Under certain circumstances, up to 12.0% max. LOI may be allowed.
** Optional. Required for ASR Minimization.
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

CHEMICAL COMPOSITION
Table 12: Mineralogy of RS&G Lime By-Product

<table>
<thead>
<tr>
<th>Analysis Parameter</th>
<th>RS&amp;G Lime By-Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite, CaCO₃</td>
<td>100</td>
</tr>
</tbody>
</table>
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

ELEMENTAL ANALYSIS
Table 13: Elemental Analysis (As-Received Sample)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>RS&amp;G Lime By-Product (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (Al)</td>
<td></td>
<td>1359.3</td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td></td>
<td>21.7</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td></td>
<td>66.1</td>
</tr>
<tr>
<td>Bromine (Br)</td>
<td></td>
<td>4.6</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td></td>
<td>625.8</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td></td>
<td>53908.2</td>
</tr>
<tr>
<td>Cerium (Ce)</td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Cesium (Cs)</td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td></td>
<td>64.0</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td></td>
<td>&lt;104.2</td>
</tr>
<tr>
<td>Dysprosium (Dy)</td>
<td></td>
<td>&lt;1.5</td>
</tr>
</tbody>
</table>

* Detection Limit Indicated by "<"
Table 13 (Continued): Elemental Analysis (As-Received Sample)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Rs &amp; G Lime By-Product (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europium (Eu)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Gallium (Ga)</td>
<td>&lt;120.8</td>
<td></td>
</tr>
<tr>
<td>Gold (Au)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Hafnium (Hf)</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Holmium (Ho)</td>
<td>&lt;1.3</td>
<td></td>
</tr>
<tr>
<td>Indium (In)</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Iodine (I)</td>
<td>&lt;4.0</td>
<td></td>
</tr>
<tr>
<td>Iridium (Ir)</td>
<td>&lt;0.00</td>
<td></td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>1792.2</td>
<td></td>
</tr>
<tr>
<td>Lanthanum (La)</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Lutetium (Lu)</td>
<td>&lt;0.00</td>
<td></td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>4754.2</td>
<td></td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>949.4</td>
<td></td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>5.2</td>
<td></td>
</tr>
</tbody>
</table>

* Detection Limit Indicated by "<"
Table 13 (Continued): Elemental Analysis (As-Received Sample)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>RS&amp;G Lime By-Product (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdenum (Mo)</td>
<td>&lt;22.6</td>
<td></td>
</tr>
<tr>
<td>Neodymium (Nd)</td>
<td>&lt;2.1</td>
<td></td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>&lt;580.8</td>
<td></td>
</tr>
<tr>
<td>Palladium (Pd)</td>
<td>&lt;204.1</td>
<td></td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>&lt;2101.3</td>
<td></td>
</tr>
<tr>
<td>Praseodymium (Pr)</td>
<td>&lt;7.1</td>
<td></td>
</tr>
<tr>
<td>Rubidium (Rb)</td>
<td>&lt;34.2</td>
<td></td>
</tr>
<tr>
<td>Rhenium (Re)</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Ruthenium (Ru)</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>Samarium (Sm)</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Scandium (Sc)</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>&lt;29.3</td>
<td></td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>&lt;2.6</td>
<td></td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>493.8</td>
<td></td>
</tr>
</tbody>
</table>

* Detection Limit Indicated by "<"
Table 13 (Continued): Elemental Analysis (As-Received Sample)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RS&amp;G Lime By-Product</td>
</tr>
<tr>
<td>Strontium (Sr)</td>
<td>404.4</td>
</tr>
<tr>
<td>Tantalum (Ta)</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Tellurium (Te)</td>
<td>0.3</td>
</tr>
<tr>
<td>Terbidium (Tb)</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>0.1</td>
</tr>
<tr>
<td>Thulium (Tm)</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Tin (Sn)</td>
<td>&lt;76.4</td>
</tr>
<tr>
<td>Titanium (Ti)</td>
<td>&lt;369.2</td>
</tr>
<tr>
<td>Tungsten (W)</td>
<td>&lt;0.8</td>
</tr>
<tr>
<td>Uranium (U)</td>
<td>8.4</td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td>&lt;3.5</td>
</tr>
<tr>
<td>Ytterbium (Yb)</td>
<td>0.2</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>4.3</td>
</tr>
<tr>
<td>Zirconium (Zr)</td>
<td>29.3</td>
</tr>
</tbody>
</table>

* Detection Limit Indicated by "<"
ROCKFORD SAND AND GRAVEL CO.
LIME BY-PRODUCT

SCANNING ELECTRON MICROGRAPHS
FIGURE 2: RS&G Lime By-Product, 100X Magnification

FIGURE 3: RS&G Lime By-Product, 500X Magnification

FIGURE 4: RS&G Lime By-Product, 1000X Magnification

FIGURE 5: RS&G Lime By-Product, 5000X Magnification
Table 14: Potential Uses for the Rockford Sand and Gravel Co.
Lime By-Product

<table>
<thead>
<tr>
<th>Type of Application</th>
<th>RS&amp;G Lime By-Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGH TECHNOLOGY APPLICATIONS</strong></td>
<td></td>
</tr>
<tr>
<td>1. Recovery of Materials</td>
<td>Very Low</td>
</tr>
<tr>
<td>2. Filler Material for Polymer Matrix (plastic)</td>
<td>Very Low</td>
</tr>
<tr>
<td>3. Filler Material for Metal Matrix Composites</td>
<td>Very Low</td>
</tr>
<tr>
<td>4. Other Filler Applications:</td>
<td></td>
</tr>
<tr>
<td>a. Asphaltic roofing shingles</td>
<td>Very Low</td>
</tr>
<tr>
<td>b. Wallboard</td>
<td>High</td>
</tr>
<tr>
<td>c. Joint filler compounds</td>
<td>Medium</td>
</tr>
<tr>
<td>d. Carpet backing</td>
<td>Very Low</td>
</tr>
<tr>
<td>e. Vinyl flooring</td>
<td>Low</td>
</tr>
<tr>
<td>f. Industrial coatings, including paints</td>
<td>Medium</td>
</tr>
<tr>
<td>g. Paper</td>
<td>Very High</td>
</tr>
<tr>
<td>5. Pozzolanic Materials (beneficiated fly ash)</td>
<td>Very High</td>
</tr>
<tr>
<td>6. Sulfur Removal</td>
<td>Very High</td>
</tr>
<tr>
<td><strong>MEDIUM TECHNOLOGY APPLICATIONS</strong></td>
<td></td>
</tr>
<tr>
<td>1. Manufacture of Cement</td>
<td>Very High</td>
</tr>
<tr>
<td>2. Manufacture of Lightweight Aggregates:</td>
<td></td>
</tr>
<tr>
<td>a. Fired</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Unfired</td>
<td>High</td>
</tr>
<tr>
<td>3. Manufacture of Concrete Products:</td>
<td></td>
</tr>
<tr>
<td>a. Low-strength concrete</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Medium-strength concrete</td>
<td>Very High</td>
</tr>
<tr>
<td>c. High-strength concrete</td>
<td>High</td>
</tr>
<tr>
<td>d. Lightweight concrete</td>
<td>High</td>
</tr>
<tr>
<td>e. Prestressed/precast concrete products</td>
<td>High</td>
</tr>
<tr>
<td>f. Roller compacted concrete</td>
<td>Very High</td>
</tr>
<tr>
<td>g. No-fines and/or Cellular concrete</td>
<td>Very High</td>
</tr>
<tr>
<td>4. Filler in Asphalt Mix</td>
<td>Medium</td>
</tr>
<tr>
<td>5. Bricks:</td>
<td></td>
</tr>
<tr>
<td>a. Unfired bricks</td>
<td>Medium</td>
</tr>
<tr>
<td>b. Fired bricks</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Clay bricks</td>
<td>Very High</td>
</tr>
</tbody>
</table>
Table 14 (continued): Potential Uses for the Rockford Sand and Gravel Co. Lime By-Product

<table>
<thead>
<tr>
<th>Type of Application</th>
<th>RS&amp;G Lime By-Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Blocks:</td>
<td></td>
</tr>
<tr>
<td>a. Building blocks</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Decorative blocks</td>
<td>Very High</td>
</tr>
<tr>
<td>7. Reefs for Fish Habitats</td>
<td>Very High</td>
</tr>
<tr>
<td>8. Paving Stones</td>
<td>Very High</td>
</tr>
<tr>
<td>9. Stabilization of Municipal Sewage Sludge</td>
<td>Very High</td>
</tr>
<tr>
<td>10. Waste Stabilization:</td>
<td></td>
</tr>
<tr>
<td>a. Inorganic wastes*</td>
<td>High</td>
</tr>
<tr>
<td>b. Organic wastes*</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Combined complex wastes</td>
<td>Medium</td>
</tr>
<tr>
<td>11. Ceramic Products</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**LOW TECHNOLOGY APPLICATIONS**

<table>
<thead>
<tr>
<th>Type of Application</th>
<th>RS&amp;G Lime By-Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Backfills:</td>
<td></td>
</tr>
<tr>
<td>a. Bridge abutment, buildings, etc.</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Trench and excavation backfills</td>
<td>Very High</td>
</tr>
<tr>
<td>2. Embankments</td>
<td>Very High</td>
</tr>
<tr>
<td>3. Site Development Fills</td>
<td>Very High</td>
</tr>
<tr>
<td>4. Stabilization of Landslides – Grouting</td>
<td>Very High</td>
</tr>
<tr>
<td>5. Landfill Cover (as a substitute for soil cover)</td>
<td>Very High</td>
</tr>
<tr>
<td>6. Pavement Base and Sub-base Courses:</td>
<td></td>
</tr>
<tr>
<td>a. Combination with cement and coarse aggregate</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Combination with cement</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Combination with on-site soils with or without the addition of cement</td>
<td>Very High</td>
</tr>
<tr>
<td>7. Subgrade Stabilization or Soil Stabilization:</td>
<td></td>
</tr>
<tr>
<td>a. Roadways/Highways</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Parking areas</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Runways</td>
<td>Very High</td>
</tr>
</tbody>
</table>

*Or a combination of inorganic and organic dredged materials from the Great Lakes and/or the Mississippi River.
Table 14 (continued): Potential Uses for the Rockford Sand and Gravel Co.
Lime by-product

<table>
<thead>
<tr>
<th>Type of Application</th>
<th>RS&amp;G Lime By-Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Land Reclamation:</td>
<td></td>
</tr>
<tr>
<td>a. Agriculture and Animal Feed</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Turf-grass (for example golf courses)</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Park land</td>
<td>Very High</td>
</tr>
<tr>
<td>9. Soil Amendment (agriculture and/or potting soil)*:</td>
<td></td>
</tr>
<tr>
<td>a. Improve infiltration characteristics</td>
<td>Very Low</td>
</tr>
<tr>
<td>b. Decrease Subsurface porosity</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Fertilizer/Composting</td>
<td>Very High</td>
</tr>
<tr>
<td>10. Flowable Fly ash Slurry</td>
<td>Very High</td>
</tr>
</tbody>
</table>

**MISCELLANEOUS CIVIL ENGINEERING APPLICATIONS**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mineral Supplement for Coal and/or for Coal Dust Control</td>
<td>Very High</td>
</tr>
<tr>
<td>2. Backfills:</td>
<td></td>
</tr>
<tr>
<td>a. Between foundations and existing soil</td>
<td>Very High</td>
</tr>
<tr>
<td>b. Retaining walls</td>
<td>Very High</td>
</tr>
<tr>
<td>c. Utility trenches</td>
<td>Very High</td>
</tr>
<tr>
<td>3. Excavation in Streets and around Foundation</td>
<td>Very High</td>
</tr>
<tr>
<td>4. Fills for Abandoned Tunnels, Sewers and other Underground Facilities (including mines)</td>
<td>Very High</td>
</tr>
<tr>
<td>5. Grouts</td>
<td>Very High</td>
</tr>
<tr>
<td>6. Hydraulic Fills</td>
<td>Very High</td>
</tr>
</tbody>
</table>

* With or without other products, such as dredged materials and/or bottom ash.
Section 5

References

[1] City of Aurora, Water Treatment Facility, information on the water purification and softening system, City of Aurora, IL, 2000.


APPENDIX 1: Modified ASTM C 422 for Particle Size Distribution

Tests conducted at the UWM Center for By-Products Utilization (UWM-CBU) had revealed that the standard ASTM C 422 test method is inadequate to measure particle size distribution of fly ashes, and similar fine grained materials, especially below 10-micron size particles. This is partially due to agglomeration caused by very fine particles of fly ash and also potentially due to chemical reaction caused by the cementitious nature of the fly ash. A significant gel formation occurs during the sedimentation testing of the fly ash. Therefore, in order to obtain more accurate test results, a modified ASTM C 422 test method was developed by the UWM-CBU for measuring particle size distribution of fly ash samples by the sedimentation technique. This UWM-CBU method differs from the standard ASTM C 422 in respect to sample preparation, sedimentation liquid, size of the sedimentation cylinder, and the hydrometer used. In the UWM-CBU modified ASTM C 422 procedure, the fly ash sample is not subjected to pretreatment prior to the sedimentation test. The particle concentration in the polymeric suspending liquid used was maintained at about three percent. This new suspending liquid had a specific gravity of about 0.8. This also necessitated the use of a different hydrometer, which can measure the density of the liquid containing suspended particles having specific gravity in the range of approximately 0.8 to 0.9. The size of the sedimentation cylinder was changed to 500 ml instead of 1000 ml used in the standard ASTM C 422 procedure. This was done to more effectively use the sedimentation liquid. In order to measure the particle size distribution, the fly ash test sample and the liquid were added in the sedimentation cylinder and were mixed by inverting the cylinder, with open end closed by hand, 60 times in one minute. Then the sedimentation readings were taken and calculations made in accordance with the ASTM Test C 422 for determination of particle size distribution. Typical results are shown in Fig. 1.