ABSTRACT

The main aim of our project was to develop technology, which converts flue gas desulfurization (FGD) sulfate-rich scrubber sludge into value-added decorative materials. Specifically, we were to establish technology for fabricating cost effective but marketable materials, like countertops and decorative tiles from the sludge. In addition, we were to explore the feasibility of forming siding material from the sludge. At the end of the project, we were to establish the potential of our products by generating 64 countertop pieces and 64 tiles of various colors. In pursuit of our above-mentioned goals, we conducted Fourier transform infrared (FTIR) and differential scanning calorimetry (DSC) measurements of the binders and co-processed binders to identify their curing behavior. Using our 6” x 6” and 4” x 4” high pressure and high temperature hardened stainless steel dies, we developed procedures to fabricate countertop and decorative tile materials. The composites, fabricated from sulfate-rich scrubber sludge, were subjected to mechanical tests using a three-point bending machine and a dynamic mechanical analyzer (DMA). We compared our material’s mechanical performance against commercially obtained countertops. We successfully established the procedures for the development of countertop and tile composites from scrubber sludge by mounting our materials on commercial boards. We fabricated more than 64 pieces of countertop material in at least 11 different colors having different patterns. In addition, more than 100 tiles in six different colors were fabricated. We also developed procedures by which the fabrication waste, up to 30-weight %, could be recycled in the manufacturing of our countertops and decorative tiles. Our experimental results indicated that our countertops had mechanical strength, which was comparable to high-end commercial countertop materials and contained substantially larger inorganic content than the commercial products. Our moisture sensitivity test suggested that our materials were non-water wettable and did not disintegrate on submerging the product in water for at least two months. Countertop polishing techniques were also established.

Pages 1 to 26 contain proprietary information
EXECUTIVE SUMMARY

Objectives: The mandate of this project was to develop value-added materials from sulfate-rich scrubber sludge. Specifically, we established technology to fabricate cost effective but marketable materials like countertops, decorative tiles, and siding material from the sludge.

To meet our objectives of developing decorative materials, the following six tasks were proposed:

- **TASK 1:** In this task we were to focus mainly on optimizing the mixes to be used for countertops, decorative tiles, and siding materials. Another important step in this task was to enhance cross-linking between sludge crystallites and our binders.
- **TASK 2:** Under this task, we focused on maintaining the highly twinned crystal growth behavior of scrubber sludge particles in our materials and yet allowing the impregnation of the polymer to form smooth textured composites. In addition, we attempted to alter physical and chemical parameters for the fabrication of composites so that enhanced mechanical strength of our decorative composites ensued.
- **TASK 3 and 4:** Under these tasks, the composites formed under task 1 and 2 were subjected to various mechanical performance tests and the ensuing data were analyzed.
- **TASK 5:** The economic analyses of our structural products was to be the focus of this task.

Introduction: About 22 million tons of FGD scrubber sludge is currently produced in the U.S. Most of it is disposed of in the landfills near power plants. In Illinois, Indiana, and Western Kentucky 6 million tons of wet scrubber sludge are currently produced. About 7,000 MW of additional capacity is expected to be wet scrubbed in the near future in response to the Clean Air Act Amendments of 1990; and this will further increase the amount of wet scrubber sludge produced annually. Since only about five percent (5%) of wet scrubber sludge is utilized nationally and the wallboard industry may be able to absorb only a portion of high-quality gypsum sludge, alternative utilization strategies must be developed to effectively utilize FGD wet scrubber sludge.

Experimental Techniques: To accomplish the aforementioned goals, we conducted Fourier transform infrared (FTIR) and differential scanning calorimetry (DSC) measurements of the binders and co-processed binders to identify the curing behavior of our binders. Using our 6” x 6” and 4” x 4” high pressure and high temperature hardened stainless steel dies, we developed procedures to fabricate countertop and decorative tile materials. The composites, fabricated from sulfate-rich scrubber sludge, were subjected to various mechanical tests.
Summary of Results: During the course of this project, the following was accomplished:

- The FTIR measurements were conducted on the as-received polymer to identify the vibrational oscillators, which could be used to measure the concentration of the polymer and cured structure of the polymer in our countertop composites.
- Our differential scanning calorimetry (DSC) measurements on as-received polymer suggested that the countertop composites should be formed at T > 60°C and not at T < 55°C as recommended by the supplier. In fact, this was born out subsequently after forming the composites at T > 60°C.
- We evaluated how the fiber content in our countertop materials affected the strength of the formed composites.
- We studied how the orientation of the fibers within our countertop composites affected their mechanical strength. Our results suggested that though the sandwich configuration gave the highest flexural strength, the incorporation of the fiber mesh at the bottom would facilitate the installation of the countertops on pre-existing countertops.
- We probed how the formation temperature controlled the strength of the formed material, and we concluded that higher formation temperature (T < 110°C) imparted better strength to the countertop material formed from sulfate-rich scrubber sludge.
- We also studied how the degree of cure affected the mechanical strength of our composite materials. It appeared that post-curing in fact decreased the strength of the countertop material.
- We formed countertop composites using conventional molding technique in which we varied the concentration of the sludge from 10-weight % to 50-weight %. However, sludge was treated to control its crystallization in our composite during molding. It appeared the flexural strength of our composites was comparable or better than the flexural strength of commercial products with similar filler concentration.
- We designed and built a vacuum die to form countertop composites under mild vacuum. Using this die, we formed countertop composites in which we varied the concentration of scrubber sludge. The concentration of the sludge in the composite was varied between 50-weight % and 75-weight %. It appeared that we could use up to 65-weight % scrubber sludge in our composites and yet obtain comparable flexural strength to that of commercial products. However, it should be pointed out that it is believed the commercial products contain only 33 % inorganic phase.
- We explored whether countertop composite’s resistance to scratching could be further enhanced by forming the composites from block copolymers. In this approach, we incorporated a polymer in addition to the polymer that was used to form countertops. Our results indicated that a second polymer, without degrading the strength of our countertops, could be added to further improve the scratch resistance of the countertop. In fact, 5-wt % of the second polymer could accomplish this without reducing the scrubber sludge crystallites in our materials.
- Our flexural strength measurements on the decorative tiles indicated that the particle size of the polymer had a crucial effect on the strength of the material, i.e., the smaller the particle size of the polymer the larger was the flexural strength of the composite.
• Our experiments suggested that 2 wt % decorative granules could be incorporated in our tile composites without compromising the strength of the material.
• We have completed the fabrication of 64 decorative tiles from scrubber sludge. Four of the tiles were mounted on a commercial backing board using commercial adhesive. Our results suggested that sludge-derived tiles could be mounted on currently existing commercial backing boards.
• Our strength and fabrication measurements suggested that a significant amount of waste and broken countertops could be recycled.
• Our strength and fabrication measurements suggested that a significant amount of broken tiles could be used to design different patterns in our decorative tiles. This approach, we believe, would considerably reduce the waste and disposal costs of our fabrication process.
• The results from above-mentioned steps were harnessed to fabricate 4” x 4” x 0.2” countertop composites with 11 different colors and patterns.
• Using data obtained from previously listed steps, we upscaled our countertop composites to 6” x 6” x 0.2” sizes. At least four different colored countertop composites were fabricated. We have now successfully fabricated 64 pieces of countertop, thus, establishing the viability of forming countertop materials from scrubber sludge.
• We examined whether aging affected the strength of our countertops and tiles. The flexural strength measurements suggested that a year of aging did not affect the strength.
• We also tested the stability of our tiles in water. After continuous immersion in water for more than a month, we so far have not observed disintegration of the tile or swelling.
• The leachate obtained from countertop and decorative tile using the ASTM D3987 procedure suggested that the concentration of selenium and arsenic were below the detection limits.
• Our detailed economic analysis indicated that our countertop product would be approximately 10 times cheaper than the current Corian and Corian-look-alike countertops. The decorative tiles would cost about $0.85 per tile.

The remainder of this report contains proprietary information and is not available for distribution except to the sponsor of this project.