Phosphorous Remediation & Recovery Product

Phosphorus is recognized as a major cause of pollution in streams and lakes and degrades water bodies. Phosphorus enters water bodies in many ways but primarily from agriculture and waste water sources. More cost-effective technologies are needed to better manage phosphorous and to leverage value from captured Phosphorous. Phosphorous comes from food and manufactured products and is found in all human and animal wastes. It is a key component of fertilizer, is used in the Food & Beverage Industry, and has industrial uses such as corrosion control.

In addition to the ecological issues, Phosphate Rock, the primary source for Phosphorous is a non-renewable resource found in limited locations in the world. Fertilizer is a major user of Phosphorous, on which world agriculture is increasingly dependent. MetaMateria’s product technology addresses both needs to better manage Phosphorous in the environment and provides an approach for recycling this important resource.

MetaMateria Technologies

MetaMateria Technologies is an advanced materials company with considerable expertise in the use of nanomaterials. We focus on unique solutions for advanced water purification and have developed a platform technology that continues to find innovative and valuable applications.

Product Approach: Remediation, Regeneration and Recovery

MetaMateria’s approach leads to higher performance products for the control of nutrients. Remediation with MetaMateria media captures more Phosphorous per unit weight and has a longer life than any other products used today. It can capture over 10% of its weight in Phosphorous. The product can be Regenerated and reused and Phosphorous can be economically Recovered in a usable form. This represents an economic alternative to both removing phosphorous from water and recovery of this important resource.

Phosphate removal is done by adsorption, not filtration (e.g. membrane). It is one of a family of environmental products that use a high surface area, porous ceramic as a substrate to hold nano-materials, bacteria colonies, or attached surfactants/ligands. Composition the porous ceramic substrate is adjusted for the planned use.

There are 3 distinct process steps in preparing the Phosphorous Media

- Preparation of a Porous Substrate
- Modification by growth of iron nano-materials
- Regeneration of Media for reuse; and to capture Phosphorous

Flexibility exists to make this product as plates or other shapes. Water easily flows into or through the media with little pressure drop (more than 10 times higher flow-rate than sand filters). This provides a durable, unique porous product for high-efficiency, engineered adsorption that is differentiated by its interconnected porosity and high surface area.
**Nano Modification** is used to grow nano-crystals on the surface of the porous platform. Shown below (left) is an example of the porous substrate with interconnecting pores. The micrograph (right) shows nano-crystals used for Phosphorous sorption that are grown on the surfaces of the porous substrate.

![Interconnecting pore structure](image1)

**Interconnecting pore structure contains nano to micron pores**

![Surfaces covered with 20-100 nm crystal fibers](image2)

**Surfaces covered with 20-100 nm crystal fibers**

The starting porous substrate will have a surface area of ~15 m²/gram. After growth of the nano-crystals, the surface area of the Phosphorous media increases to 60-70 m²/gram and has a density of ~0.65 gram/cc. This product contains open and interconnected porosity, allowing water to easily flow into or through the media. Sand, by comparison, only has about 0.5 m²/gram of surface area. The result is our product has over 100x the available surface area of other products.

**Capacity** of the Phosphorous media depends upon concentration, as seen below using 24 hour batch tests. Silica and nitrate are potential competing ions but they did not affect capacity. The pH did affect capacity and it was 24% higher at a pH of 6.5 than at 8.5.
Early work on this nano-modified product began in 2007 when screening tests showed encouraging results of an early version of the Phosphorous media. Capacities shown below give results obtained for this early product compared with an iron activated alumina and two commercial products. The early MetaMateria product had a capacity over 40 mg/g. Much of the progress on this media occurred in 2011 under a Phase I SBIR funded by the National Science Foundation, which continues as a Phase II started in 2012. Today's media shows a capacity of 100 mg/g when tested at 8-10 ppm (mg/l) of influent phosphorous (as phosphate) and capacity is over 130 mg/g at 100 ppm. When Phosphorous influent is 1 ppm, capacity is typically ~40 ppm.

Time in contact with the influent water and water flow rate is also important. Shown below is a graph showing that after 96 hours in static water, the phosphorous dropped from 10 ppm to nil. The right graph shows the effect of circulation of water in the container. In 1 hour, Phosphorous dropped to under 1 ppm in circulated water, while without circulation, it only dropped to 5 ppm.
**Media Regeneration** is done by chemically removing phosphorous and followed by preparing the nano-modified substrate for reuse. Basic chemical processes are used for regeneration and about 98% of the Phosphorous is removed. The sorption capacity remains similar, at 10 uses, to the original material as seen in the Bar graph.

It is anticipated that media will be packaged into cartridges or modules that will be designed into systems. Cartridges will be returned to a regional processing station for regeneration and not done on site, except for large installations where the economics warrant a dedicated facility. Ten (10) regenerations are expected without a significant drop in the adsorption capacity.

The ability to regenerate the product for reuse can easily result in a 40-50% savings to customers, providing a cost-effective alternative to chemical treatment. Once regeneration is no longer practical, this alumino-silicate media could be pulverized and disposed in agricultural fields to utilize any residual Phosphorous.

**Phosphorous Recovery** occurs from the liquids containing soluble phosphorous removed from the media during regeneration. Several approaches can be used for recovery of Phosphorous. The approach used to date is to add calcium and recover phosphorous as a calcium phosphate precipitate \([\text{Ca}_3(\text{PO}_4)_2]\), which is separated from the regeneration liquid by either centrifugation or filtration. The precipitate is then dried. It has a high surface area (188 m²/gram) indicating fine particles. XRD and chemical analysis confirm the crystallinity and purity of the recovered Phosphorous. Phosphorus recovery is a simple incremental process to occur at a regional processing facility where media regeneration will occur.

**Phosphate Product Summary**

Our ability to Remediate, Regenerate and Recover Phosphorous in a highly cost-effective adsorption basis is unique to the water and environmental industry.

✓ **Unique composite** containing nano-materials grown in an open porous media
✓ **High Phosphorous sorption capacity** (5-10 times that of other media)
✓ **Removes Phosphorous at all concentrations**
  Above 5 ppm: it removes over 100 grams of Phosphorous/Kg-product
  Below 1 ppm: it removes over 40 grams of Phosphorous/Kg-product
✓ **Product can be re-used** after removing sorbed Phosphorous
✓ **Eco-friendly and is safe for disposal**
✓ **Patent Pending**

**For More Information**

**Dr. J. Richard Schorr**
CEO, MetaMateria Technologies
jrschorr@metamateria.com
614-599-0939 (mobile)

**Mr. Stephen Anderson**
VP Business Development
sanderson@metamateria.com
614-623-1210 (mobile)