Phosphate Removal Media for Aquariums: Granular Ferric Oxide Comparison to Activated Alumina and Phosphate Removal Ion Exchange Resin

Thomas Langdo, Ph.D., Chief Technology Officer, Kolar Labs

Abstract
To discover which phosphate removal media works most effectively, granular ferric oxide, activated alumina and phosphate removal ion exchange resin were studied in a controlled seawater environment. Removal performance was determined through amount of phosphate removed from the seawater and through a price analysis. Granular ferric oxide outperformed the two other media in all categories, removing the most phosphate and doing so most economically.

Introduction
Phosphorous is a vital nutrient that requires careful management for a well-functioning marine aquarium environment. Phosphorous naturally occurs in two general forms: inorganic phosphate and organic phosphate. Simply, inorganic phosphates lack carbon atoms in their structure while organic phosphates have phosphorus bonded to carbon atoms. The most common form of inorganic phosphate is the PO4 ion called orthophosphate which is readily used in biological processes by organisms such as corals, plants and algae. Because inorganic phosphate can easily be used by organisms in life processes, it is much more of a concern to aquarists than organic phosphate forms that are not always usable. Elevated inorganic phosphate levels have several negative effects on aquariums such as encouraging excessive algae growth and reducing calcification in corals.

Fortunately, there are several approaches available for inorganic phosphate management. Two common approaches use metal oxide-based adsorption media or polymer ion-exchange resin materials to bind inorganic phosphates to maintain desired phosphate levels. There are many different phosphate removal media available, and their performance depends on the material composition, the manufacturing processes used to fabricate the media, and water conditions.

Materials and Methods
We implemented a controlled inorganic phosphorous isotherm study to determine the removal performance of three different common materials in a commercial seawater mixture: Bayoxide® E-33 Granular Ferric Oxide (GFO) adsorption media, an activated alumina adsorption media, and a phosphate removal ion exchange resin. Isotherms represent the equilibrium balance of phosphate in the water with the phosphate removed by media. These isotherms are used to determine the phosphorous removal capacity of the media in marine aquarium applications. Furthermore, combining the removal performance with media costs allows comparison of the economics of the phosphate removal process for the different media.

Six isotherm samples with varying phosphate concentrations were created for each media for a total of 18 samples. Samples were given two weeks to come to equilibrium to demonstrate the removal characteristics. More detailed information on the experimental methods used in the isotherm study is listed in the Appendix. The phosphate removal isotherm results are shown in Figure 1. Phosphate removal capacity is on the Y-axis in milligrams (mg) of phosphate removed per gram of media. The equilibrium concentration of phosphate with the removal media is on the X-axis as parts per million (ppm) of inorganic phosphate in seawater. At this phosphate water composition, the media is saturated with phosphate and has reached capacity.

Results and Discussion
Over the whole measured phosphate range, Bayoxide® E-33 GFO shows superior phosphate removal capacity compared to activated alumina and the phosphate removal resin. At a low phosphate water concentration of 0.1 ppm, GFO exhibits a capacity of over 12mg phosphate removed per gram media—more than 18 times higher than aluminum oxide and 8 times higher than the phosphate removal resin at the same condition. Both the activated alumina and phosphate removal resin show similar removal performance over the phosphate concentration range investigated and demonstrate much lower capacities compared to GFO. Furthermore, in additional testing Bayoxide® E-33 GFO also exhibited the fastest removal kinetics of the three media, indicating strong affinity for phosphate binding and short times (1 to 2 days) to dramatically reduce phosphate levels. Bayoxide® E-33 GFO showed excellent phosphate removal performance compared to activated alumina and phosphate removal resin in marine environments resulting in a much higher removal capacity and faster removal process.

An additional important consideration is media cost. A brief survey was conducted of the best online pricing found for the three different media for 0.5 liters or 500 gram product sizes and is tabulated in Table 1 with calculations for price per gram of media. This pricing data was used to determine the media's phosphate removal performance per dollar of media. This is an important metric, since one can increase phosphate removal in an aquarium by using more media but at an added cost. The isotherm removal curve from Figure 1 is shown in Figure 2 after being compensated for the media pricing, resulting in a removal cost isotherm.

In this removal cost isotherm, Bayoxide® E-33 GFO shows a greater phosphate removal performance compared to the activated alumina and phosphate removal resin in marine environments. At 0.1 ppm phosphate concentration, Bayoxide® E-33 GFO exhibits a capacity of 274mg phosphate removed per dollar of media. Simply explained, this means that given the pricing in Table 1, one dollar of GFO media will remove 274mg of phosphate from an aquarium, a large amount compared to other methods. This GFO phosphate removal capacity is more than 9 times higher per dollar than activated alumina and more than 26 times higher compared to the resin. Not only does Bayoxide® E-33 GFO show much higher phosphate removal capacity on a per-gram basis, but it also shows dramatically more favorable removal economics than comparable methods.

Conclusion
Based on the isotherm testing, GFO is the superior phosphate removal material with the fastest removal kinetics and highest phosphate removal capacity on a per-gram and per-dollar basis compared to activated alumina and the phosphate removal ion exchange resin.

In addition, GFO has another advantage over activated alumina as it is an iron-based formulation. Since GFO lacks aluminum in its composition, it does not have the potential to release aluminum into the aquarium like activated alumina materials which can have a deleterious effect on marine life.

Figure 1: *Phosphate removal isotherms for Bayoxide® E-33 GFO, activated alumina, and phosphate removal resin in commercial seawater. Note: Bayoxide® E-33 GFO shows superior phosphate removal capacity over activated alumina and phosphate removal resin across all phosphate conditions studied.*

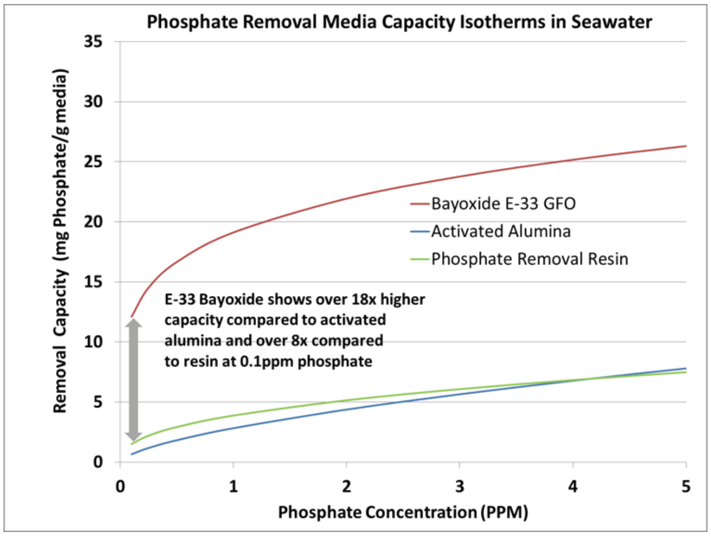
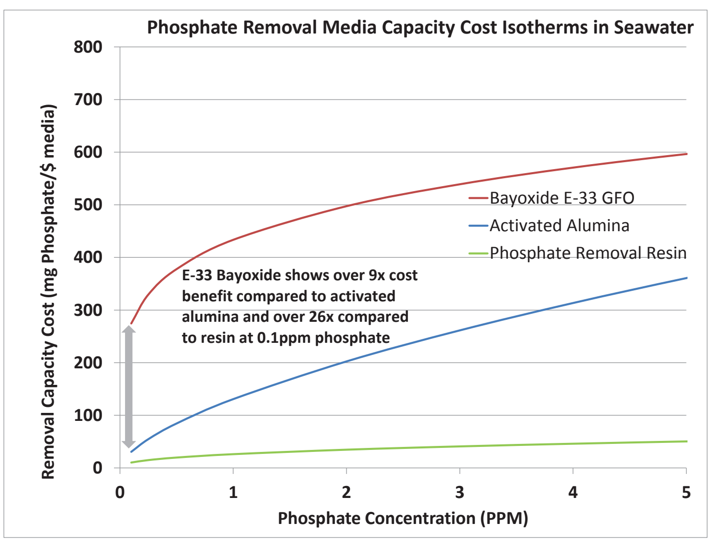


Table 1: *Pricing used for phosphate removal economics isotherm determination.*

	Bayoxide® E-33 GFO	Activated Alumina	Ion-Exchange Resin
Size	500 grams	0.5 L (500 grams)	0.5 L (400 grams)
Online Price ($)	22.05	10.80	59.49
Price ($/gram media)	0.044	0.022	0.149

Figure 2: *Isotherm economics determination for Bayoxide® E-33 GFO, activated alumina, and phosphate removal resin using pricing from Table 1 and data from Figure 1. Note: Bayoxide® E-33 GFO shows superior phosphate removal economics over activated alumina and the phosphate removal resin across all phosphate conditions studied.*



Appendix

These are the process details used to determine the isotherm data:

- Distilled water was used in all testing.
- The Bayoxide® E-33 Granular Ferric Oxide (GFO) and commercial activated alumina were washed to remove any dust or fines, dried at 100°C for 2 hours and stored in sealed bottles prior to use in isotherms.
- The phosphate removal ion exchange resin was used wet, “as is.”
- All removal media were weighted out by a laboratory balance with 0.01 gram resolution.
- Laboratory grade KH2PO4 was used as the phosphate source.
- Commercial seawater was mixed according to manufacturer directions to create seawater with a final density of 1.026 determined by a floating hydrometer.
- Isotherms were carried out by varying the starting phosphate concentration in 250 mL of seawater solution with 1 gram of removal media for each media for 6 different phosphate concentrations.
- An isotherm equilibrium time of 14 days (2 weeks) was chosen to allow the phosphate concentration in solution to come to equilibrium with the removal materials and minimize any time-based kinetic effects.
- Temperature was maintained at 22°C (72°F) for the duration of the isotherm testing.
- The resulting phosphate concentrations were measured by a commercial colorimeter using the ascorbic acid method.