Reasoning for the IFGEM a.k.a. Iron, Clay, and Sand (ICS) filter media

Marty Wanielista, August 2023

This information is provided to the SFWMD, Richard Lott.

1. Proposed BMP effectiveness was determined by laboratory studies which included a comparison to an existing media, namely BAM (B&G CTS) and as reported in two patents as well as the experience Dr. Wanielista had serving on a National Academy of Science review committee for iron enhanced sand filters in Minnesota.
2. The patents # 10,696,567 June 30, 2020, and #10,787,373 September 29, 2020, establish a particular type of clay and iron filings of a certain size to remove nitrogen and phosphorus. All percentages of iron and clay are protected by the Patents. The exact mix percentage was then based on field applications and performance.
    a. Data from the Minnesota iron enhanced filters were reviewed, and clogging (slow treatment of water) noted from the use of some iron filing mixes. By weight, 5-8% of iron filings (about 3-5% by volume) are specified for ICS to minimize clogging and well as to achieve removal (Minnesota Stormwater Manual, stormwater.pca.state.mn.us design criteria). Recommended is 5% by volume as the maximum iron filing for the ICS mix.
    b. For the clay %, recommended is 4%. Removal data to support the percent of clay is found in patent #10.787,373 (table 16). The data in table 16 are for percent removal using three different influent nutrient concentrations. The clay is mixed with sand and 5% iron. Sand must follow a size distribution, have minimum phosphorus, and clay content. Up to 8% clay may be reasonable to use for removal, however 6% and 8% clay in media has a low treatment rate and in general lower removal.

Influent	nitrate 0.9mg/L, phosphorus 0.3mg/L			nitrate 1.3mg/L phosphorus 0.5mg/L			nitrate 1.7mg/L phosphorus 0.7mg/L		
Clay content	Ammonia removal	TP removal	TN removal	Ammonia removal	TP removal	TN removal	Ammonia removal	TP removal	TN removal
2%	98.17%	83.76%	91.50%	96.11%	81.10%	90.94%	95.14%	91.76%	93.94%
4%	87.21%	93.00%	76.61%	77.10%	79.11%	83.42%	89.04%	79.98%	87.02%
6%	89.92%	68.84%	87.76%	91.98%	95.47%	83.07%	84.62%	70.34%	83.94%
8%	61.46%	78.43%	83.01%	70.61%	78.37%	79.42%	85.39%	76.90%	82.90%

Before ICS is used in the State of Florida, effectiveness and design must be documented and is the initiative of the responsible party (vendor, municipality, university, as examples). The initiative must include data from the laboratory (as in the Patents) or from out-of-State field monitoring programs. ICS is acceptable as judged by the issuance of a permit for installation. The ICS installation is a one-acre filter that is operating year around and construction has been completed. The issuance of a permit for ICS includes a monitoring program for validation of effectiveness. The monitoring program has started.

Additional support information follows:

c. I use data on removal from referred publications with the data from these publications also included in two patents, namely # 10,696,567 June 30, 2020, and #10,787,373 September 29, 2020. The claim of the patents is that nutrient removal is enhanced with the synergistic reaction of iron and clay. The media mixes, identified as BAM, IFGEM-1, IFGEM-2, and IFGEM-3 with the following compositions were used in a laboratory setting to determine removal effectiveness:

Composition	BAM	IFGEM-1	IFGEM-2	IFGEM-3
a. Media Matrix Composition by Volume				
Sand (%)	85	96.2	80	83
Tire crumb (%)	10	—	10	10
Clay (%)	5	—	5	2
Iron filing (%)	—	3.8	5	5

d. The TP and TN removal effectiveness for three different influent concentrations from patent # 10,787,373 (table 26) are listed below with supporting publications as listed at the end.

Column	Port	Total Nitrogen (%)	Total Phosphorus (%)
Influent nitrate = 0.9 mg/L, phosphate = 0.3 mg/L			
BAM	Effluent	73.14	10.11
IFGEM 1	Effluent	55.10	28.84
IFGEM 2	Effluent	85.39	81.65
IFGEM 3	Effluent	80.83	50.19
Influent nitrate = 1.3 mg/L, phosphate = 0.5 mg/L			
BAM	Effluent	46.09	−176.82
IFGEM 1	Effluent	48.28	4.19
IFGEM 2	Effluent	90.46	60.26
IFGEM 3	Effluent	96.86	76.38
Influent nitrate = 1.7 mg/L, phosphate = 0.7 mg/L			
BAM	Effluent	66.62	63.85
IFGEM 1	Effluent	70.70	92.81
IFGEM 2	Effluent	93.94	91.64
IFGEM 3	Effluent	94.35	92.43

e. Not considering the negative removal of BAM in the second influent condition above,
For BAM: average removal for TN is 62% and for TP is 37%
For IFGEM 1: 3.8% iron and no clay, average removal for TN is 58% and for TP is 42%
For IFGEM 2: 5% iron and clay @5%, average removal for TN is 90% and for TP is 78%
For IFGEM 3: 5% iron and clay @2%, average removal for TN is 91% and for TP is 73%

f. Conclusions related to effectiveness and components:
   i. Iron and clay media enhanced sand removes more than a media with just iron enhanced sand (IFGEM 1 compared to both IFGEM 2 and IFGEM 3).
   ii. Iron without clay removes about the same as BAM (BAM compared to IFGEM 1).
   iii. The amount of clay over 2% (IFGEM 2 compared to IFGEM 3) does not appear to substantially affect the TN and TP removal.
   iv. Additional support publications for removal effectiveness are listed below.

g. Dissolved Organic Nitrogen may be present in the source water. Removal of DON is possible with the use of IFGEM. Expected removals are reported in the publications by Valencia (2020) and Chang (2018a) listed below. Based on three laboratory column studies with DON being approximately 38% of the total nitrogen and three TN influent concentrations of approximately 1.5, 1.8 and 2.3 mg/L, the average DON removal using IFGEM was about 81%.

h. Infiltration (treatment) rate is the primary design parameter. Too much iron oxide and clay will limit the treatment rate to near zero or at a rate which is too expensive to build. From Patent # 10,696,567 June 30, 2020 (table 2), the material characteristics are shown. Natural soil was used which had a 6.5% clay content.

Material Characteristics

	IFGEM1	BAM	Natural Soil	IFGEM2
Density (g/cm^3)	2.73	1.39	2.36	2.60
BET Surface Area (m^2/g)	0.3142	0.7059	9.3712	1.3963
Porosity (%)	36.16	40.10	40.43	37.31
Infiltration Rate (cm/s)	0.028	0.026	0.003	0.017

With 6.5 % clay (Natural Soil), the infiltration (treatment) rate is the lowest at 4.25 inches per hour (0.003 cm/sec). A faster treatment rate that maintains removal would result in a smaller facility. IFGEM1, IFGEM2 and BAM have faster rates. BAM with 5% clay and 10% tire crumb has a treatment rate of 37 inches per hour (0.026 cm/sec). Tire crumbs in BAM results in a higher treatment rate because of larger size particles. IFGEM1 without tire crumb but with 3.8% iron treated at 40 inches per hour (0.028 cm/sec). IFGEM2 with tire crumb can treat at 24 inches per hour (0.017 cm/sec). Conservatively, the ICS mix of 91% sand, 5% tire crumbs, and 4% clay is designed using a treatment rate of 10 inches per hour. This is based on experience with BAM whose field derived infiltration rate after at least 10 years of operation is at least 10 inches per hour.

The depth of filter specified by the permit agencies in Florida is a minimum of 24 inches. This depth is believed to minimize short circuiting or a reduction in average residency time. Since each filter reported in the Patents as well as used in the field applications is at least

24 inches in depth, the residence time based on the column packed with media is the media depth divided by the treatment rate. For ICS, the residence time is 2.4 hours, or twenty-four inches divided by ten inches per hour.

Warranty

The mix composition is under warranty as delivered to the installation site. This is done with a mixing facility that reports on the sampling for the source materials and mix specifications. The mix has no organic materials and thus is not expected to degrade over time.

Support Publications

Erickson, AJ, Gulliver JS, and Weiss, PT. (2007). "Enhanced Sand Filtration for Storm Water Phosphorus Removal." JOURNAL OF ENVIRONMENTAL ENGINEERING © ASCE, May.

Chang, N-B, Wen, D, and Wanielista, MP. (2018). "Impact of Changing Environmental Factors and Species Competition on Iron Filings-Based Green Environmental Media for Nutrient Removal in Stormwater Treatment." AIChE. Published online in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/ep.13087.

Chang, N-B, Wen, D, McKenna. M., and Wanielista, MP. (2018a). "The Impact of Carbon Source as Electron Donor on Composition and Concentration of Dissolved Organic Nitrogen in Biosorption Activated Media for Stormwater and Groundwater Co-Treatment". Environ. Sci. Technol. 2018, 52, 9380−9390.

Valencia, A, Chang, N-B, Wen, D, Ordonez, D, and Wanielista, MP. (2019). "Optimal Recipe Assessment of Iron Filing-Based Green Environmental Media for Improving Nutrient Removal in Stormwater Runoff". ENVIRONMENTAL ENGINEERING SCIENCE Volume 36, Number 10.

Valencia, A., Ordonez, D., Wen, D, McKenna. M., Chang, N-B, and Wanielista, MP. (2020). "The interaction of dissolved organic nitrogen removal and microbial abundance in iron-filings based green environmental media for stormwater treatment." Environmental Research, 109815, 0013-9351/ Elsevier, June.

Erickson, AJ, Kozarek, JL, Kramarczuk, KA, and Lewis, L. (2021). "Biofiltration Media Optimization – Phase 1 Final Report." Project Report No. 593, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN. January 2021.