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Fundamentals of Vortex Flow

Gravity is the Dominant Force in Grit Removal

Wastewater Application Sheet

From the time that it was conceived to add a curve to the flow path and utilize a round grit chamber to enhance grit capture (Geiger 1942), through development of the swirl concentrator (Smisson 1967) to utilizing the swirl concentrator as a grit separator (APWA 1974) and beyond, design theory for vortex separators has been based on removing a specific size of particle with a known or assumed specific gravity from flows.

Virtually all studies, models and technical papers agree that, for a given size basin, when flow is reduced capture efficiency increases and vice versa, (Geiger, Smisson, APWA, Grownowska-Szneler, Chein, McNamara, Pretorius) indicating that sedimentation under the force of gravity is the main mechanism for grit removal. While centrifugal forces enhance separation by elongating particle flow path and residence time, gravitational force remains dominant.

There is no commonly used mathematical model or equation used for sizing vortex grit basins. The three criteria most influential on capture efficiency are particle settling velocity, basin size and flow rate. Capture efficiency can also be affected by inlet velocity, inlet size, shape and placement in the vessel, outlet geometry and location, floor slope, ratio of influent to underflow, and whether a rotating impeller is used.

Many of the already mentioned papers along with results from lab experiments, testing at full scale plants, and mathematical & CFD models of vortex basins used to separate solids were evaluated by Pretorius (2012) looking for a mathematical model or equation for use in designing vortex grit basins.

Pretorius concluded that the use of surface overflow rate (SOR) should be the key parameter determining capacity in the design of vortex grit basins. SOR is more conservative than a Froude number similarity which aligns well with general industry philosophy. SOR can also be easily adjusted to accommodate site-specific grit characteristics such as particle size and specific gravity. Pretorius included discussion on several of the above-mentioned factors that can impact capture efficiency. These factors did not change his conclusion that surface overflow rate is our best parameter as the basis of design.

Based on Newton's laws of motion, a 106 micron grain of sand with a specific gravity of 2.65 has a settling velocity of 0.34 in/sec. Converting this settling velocity to a SOR (Vs=Q/A) yields 21,024 gpd/ft^2 or 14.6 gpm/ft^2. Fitting with general industry philosophy, a measure of conservatism is generally applied.

Using standard sizing and headloss, virtually every manufacturer

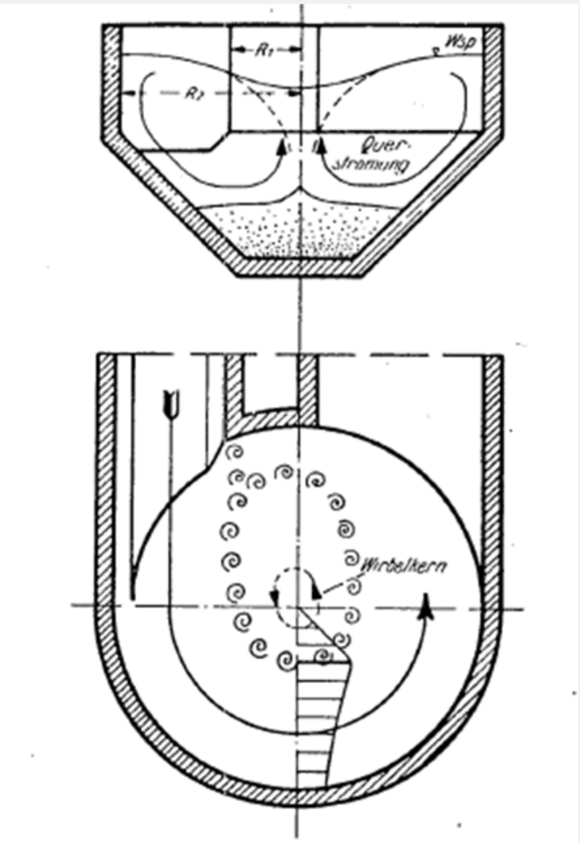

Figure 1. Original proposed vortex grit basin design (Geiger, 1942)

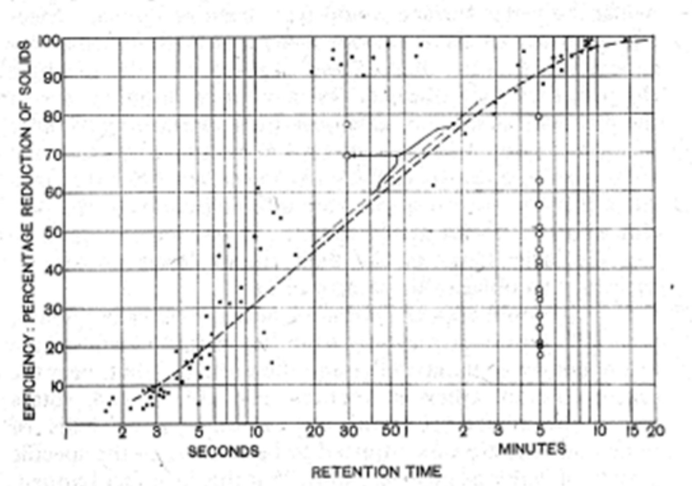

Figure 2. Variation of efficiency with retention time (Smisson, 1967)

of mechanically induced vortex (MIV) units will confirm the technology cannot remove 95% of grit 106 micron and larger. MIV units are designed to operate at peak SOR of 45-110 gpm/ft² which is significantly higher than the 14.6 gpm/ft² required according to Newton's laws. Traditional MIV performance is outlined below. However, Pretorius describes these performance claims as "optimistic".

Table 1. Standard MIV Performance
95% removal of grit > 300 micron (50 mesh)
85% removal of grit > 212 micron (70 mesh)
65% removal of grit >150 micron (100 mesh)

Table 1. Standard performance claim for mechanically induced vortex grit units

If sized based on SOR, performance claims would be significantly different. Table 2 outlines expected particle size of spheres of silica sand, 2.65 SG, that would be expected to be removed based on SOR and Newton's Law. This reduced performance expectation has been confirmed by independent testing performed by Hampton Roads Sanitation District at three wastewater treatment plants.

Testing at all three plants indicated conventional sizing of MIV technology does not meet expected performance. Data consistently indicates higher capture efficiency of larger particles, which are expected to settle more quickly, and lower removal of smaller particles, which would settle more slowly, aligning with sizing MIV systems based on SOR.

Table 2. MIV Performance Expectation

Chamber Diameter	Maximum Flow	Chamber Area	Surface Overflow Rate	Est. Perf. Newton's Law
(ft)	(mgd)	(ft²)	(gpm/ft²)	(micron)
6	1.0	28.3	24.6	150
7	2.5	38.5	45.1	225
8	4.0	50.2	55.3	250
10	7.0	78.5	61.9	275
12	12.0	113.0	73.7	300
16	20.0	201.0	69.1	300
18	30.0	254.3	81.9	350
20	50.0	314.0	110.5	450
24	70.0	452.0	107.5	450
32	100.0	804.2	86.3	350

Table 2. Performance expectation of mechanically induced vortex grit units based on Newton's Law and surface overflow rate

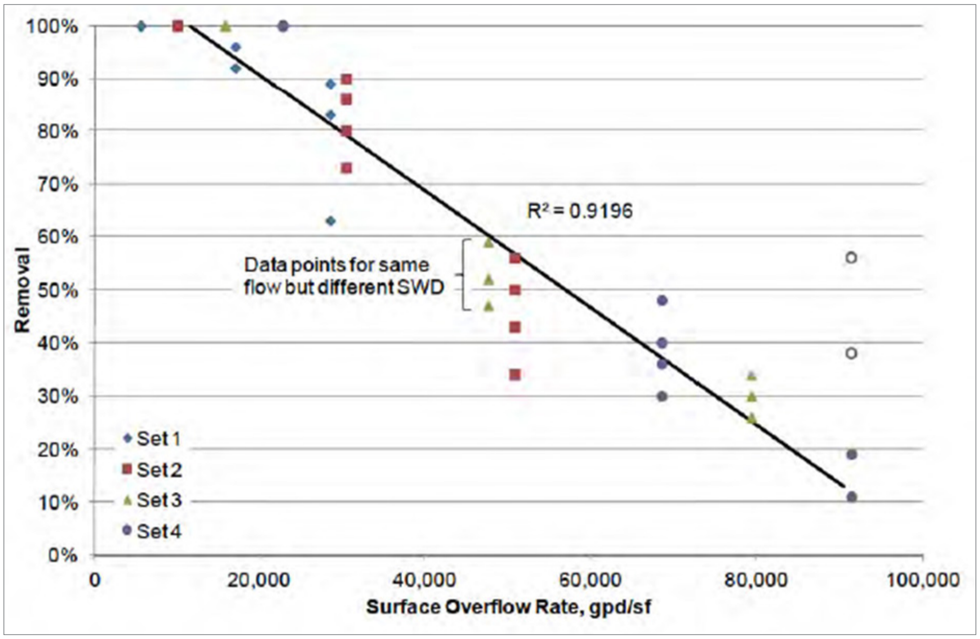

Figure 3. Removal as a function of SOR (Data from APWA 1974) (Pretorius 2012)

Table 3. % Removal Efficiency

	#50 Mesh (>297µm)	#70 Mesh (<297µm - >211µm)	#100 Mesh (<211µm - >150µm)	Total % Removal (150 µm & larger)	Total % Removal (106 µm and larger)
Claimed Performance	95%	85%	65%		
Actual Measured Performance and Sample Dates at VIP Vortex					
Sun, 05/20/07	57.7	29.8	22.7	45.3	44.3
Mon, 05/21/07	60.5	26.8	23.2	45.1	43.7
Tue, 05/22/07	59.3	33.2	27.9	43.3	43.3
Actual Measured Performance and Sample Dates at Ches-Eliz Vortex					
Thu, 05/17/07	72.6	19.1	7	48	45.8
Fri, 05/18/07	77.8	28.9	14.7	52	50.9
Actual Measured Performance and Sample Dates at Nansemond Vortex					
Tue, 03/04/08	44.4	29.4	4.4	22.8	16.3
Wed, 03/05/08	58.1	36.4	16.3	31.1	29.2

Table 3. Removal efficiencies of grit unit processes (McNamara 2009), Relative Performance of Grit Removal Devices (McNamara 2014)

Some claim the addition of baffles improve performance. Baffles can be used to increase residence time and minimize short circuiting. Baffling the inlet will increase headloss and improve performance if the headloss is sufficient to increase the centrifugal velocity well above the force of gravity. Baffling the effluent will increase outlet velocity which has the opposite of the desired effect as the velocity increase can draw suspended grit from the basin.

As shown by Computational Fluid Dynamics performed on a 20-ft MIV basin with baffles, rise velocity increases near both the inlet and outlet baffles creating hot spots which may provide scope for particle escape.

Baffles do not increase separator size or decrease surface overflow rate. The use of baffles in MIV technology has been associated with elevated performance claims of 95% removal of grit > 106 micron (140 mesh). There is no independent or peer reviewed testing to support such claims. In fact, independently tested baffled units have shown only minimally improved removal efficiency (McNamara 2012, Mayers 2016). Given the high SOR allowed with MIV technology it is not difficult to understand why performance beyond the standard MIV performance outlined above should be viewed with skepticism.

For the reasons outlined above, a vortex basin with a SOR of 45 to 100+ gpm/ft² will not capture particles 106 micron and larger. To effectively capture 106 micron grit in a 16' diameter mechanically induced vortex unit, for example, the maximum flow to the unit would need to be approximately 4.25 mgd rather than 20 mgd which is typically stated.

When designed to capture grit 106 micron and larger the Hydro International HeadCell® is designed with a SOR less than the 14.6 gpm/ft², providing an industry standard measure of conservatism in design. Performance of the HeadCell® has been verified by independent third parties at multiple locations.

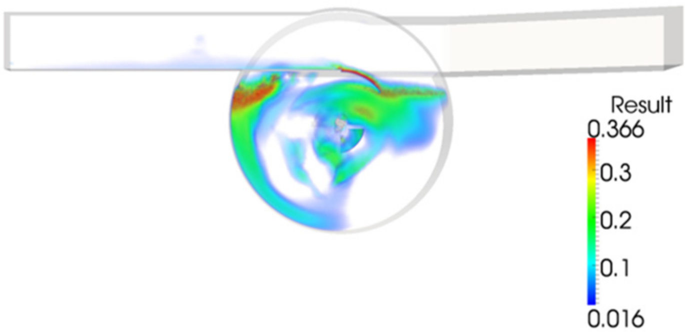

Figure 4. Increase in rise velocity shown at inlet and outlet baffles (© 2020 Hydro International)

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