Effects of varying inclination angle on Archimedes screw generator power production with constant head

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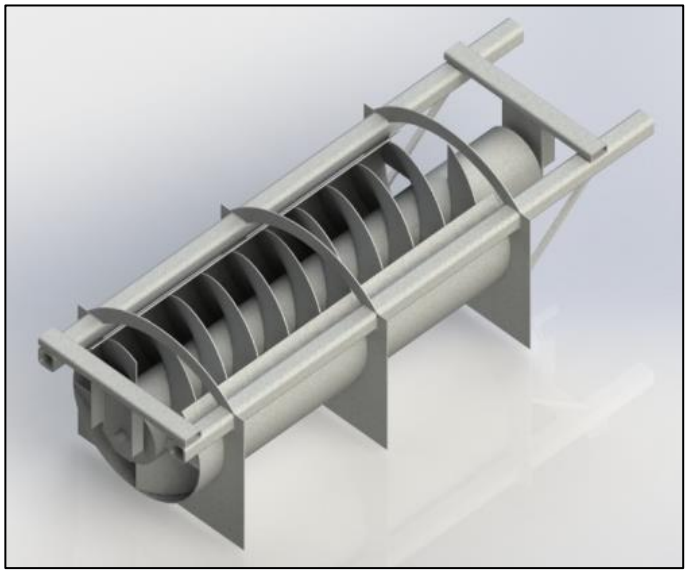
Overview

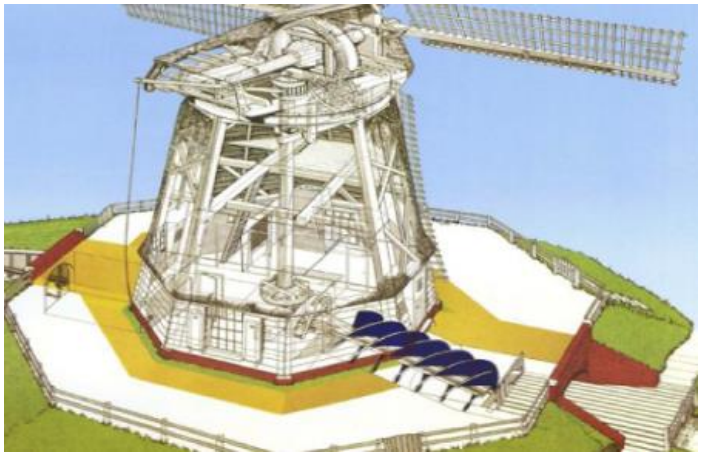
1. Introduction to Archimedes screws for hydropower
2. Experimental Methods
3. Results
4. Conclusions



Three-flighted lab-scale Archimedes Screw

Archimedes screw generators (ASGs)

- Originally implemented as pumps
  - Which they still serve as in contemporary society
- Implemented as a hydropower generator in 1991
  - German Patent Number: DE4139134A1, 1997
- Has a place in the hydroelectric market due to its three main functional advantages
  1. Eco-friendliness
  2. Low Cost
  3. Unique Operational Range

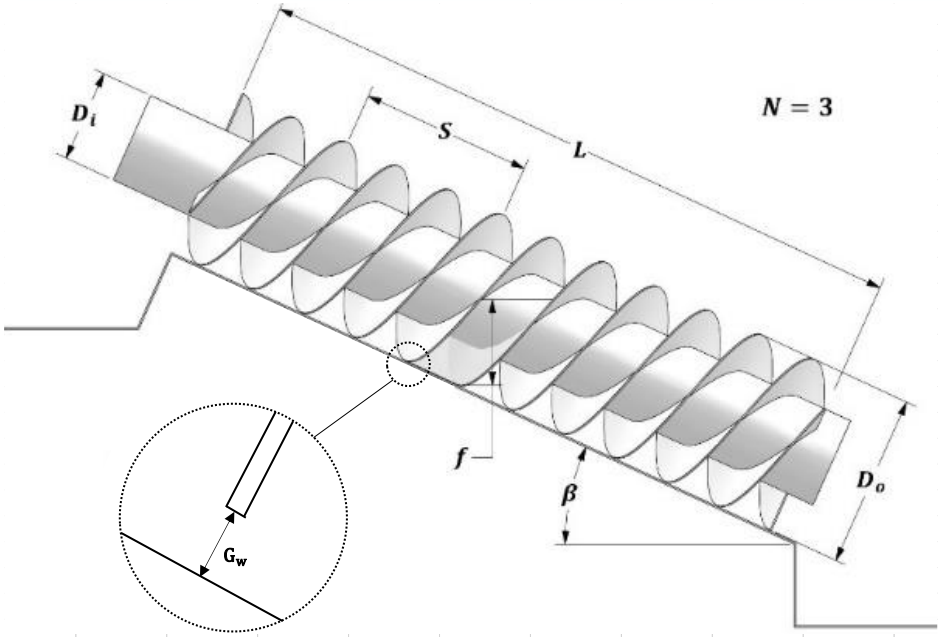


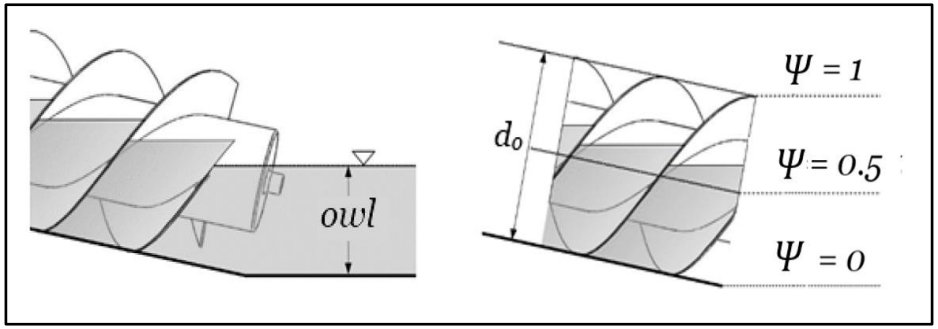
Archimedes screw pump in a Polder Mill (Greenbug Energy, 2016).

Archimedes screw generator installation (Western Renewable Energy, 2019).

Archimedes screw generators (ASGs)

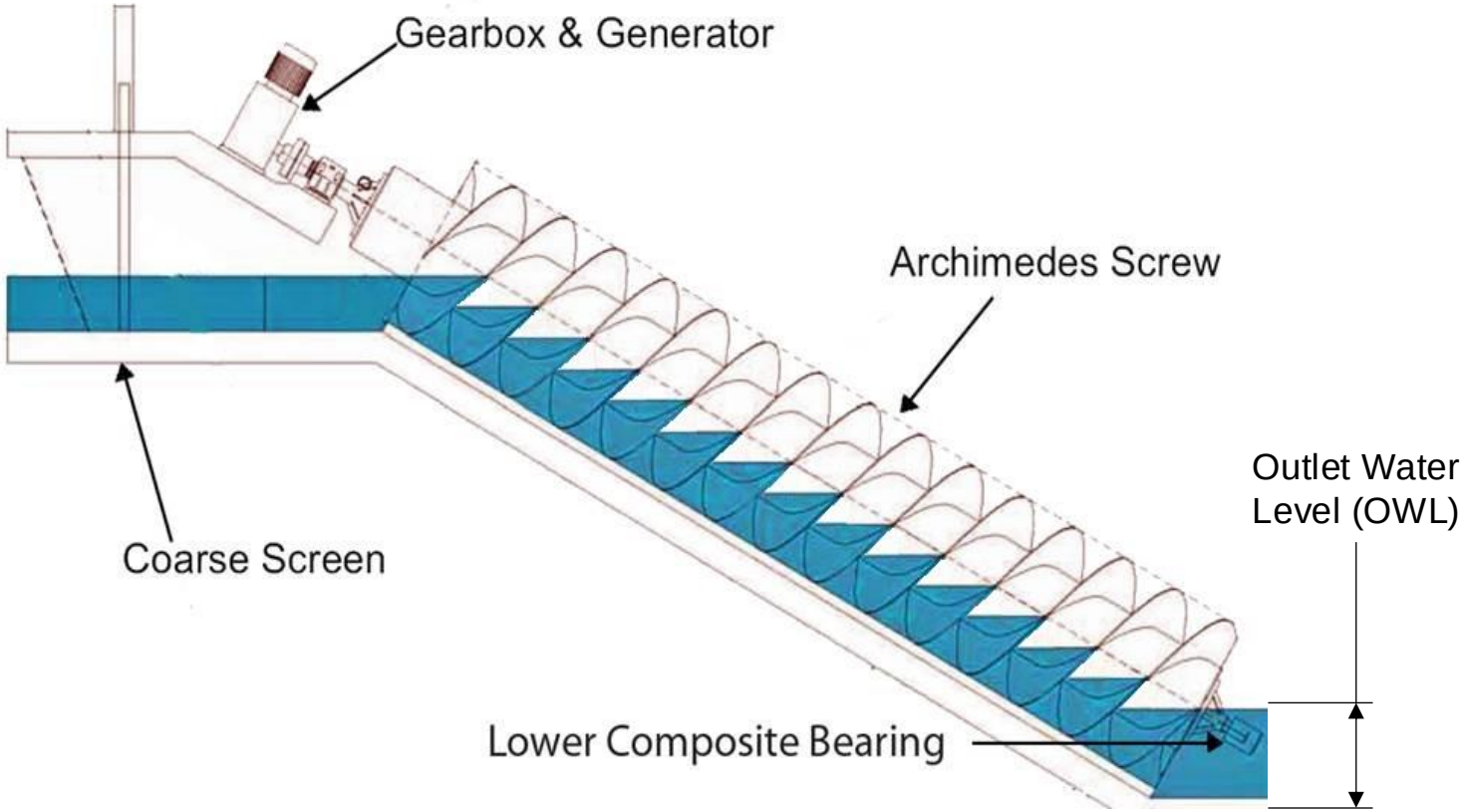
- Helical array of blades wrapped about a central cylindrical tube
- Defined by the following parameters
  - D_o = Outer Diameter
  - D_i = Inner Diameter
  - L = Flighted Length
  - S = Screw Pitch
  - N = Number of Blades
  - β = Inclination Angle
  - f = Fill Height Ratio
  - G_w = Gap Width
  - Ψ = Outlet Water Level (owl)



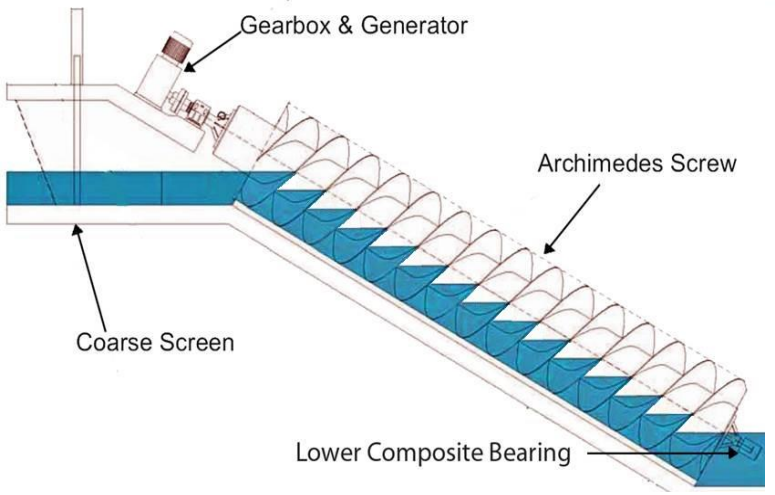


Archimedes screw generators (ASGs)

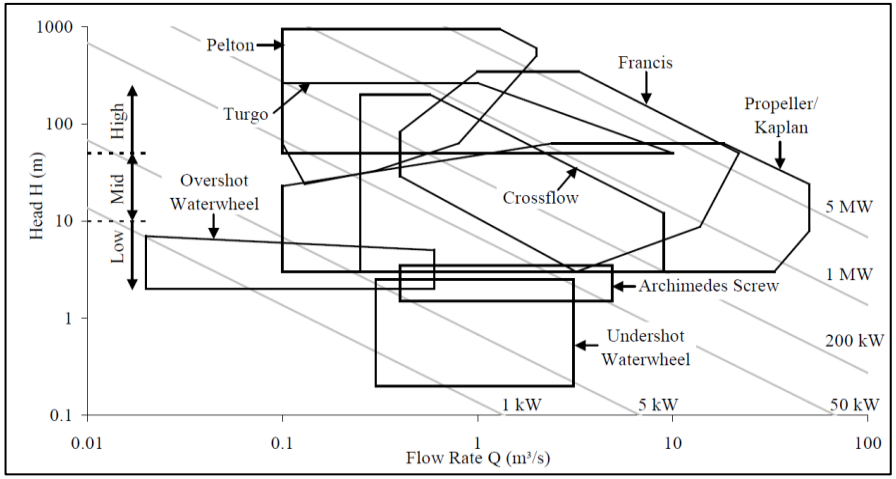
- Distribution of hydrostatic pressure due to water in screw imparts net torque, turns the screw, which turns a generator



Advantages of ASGs

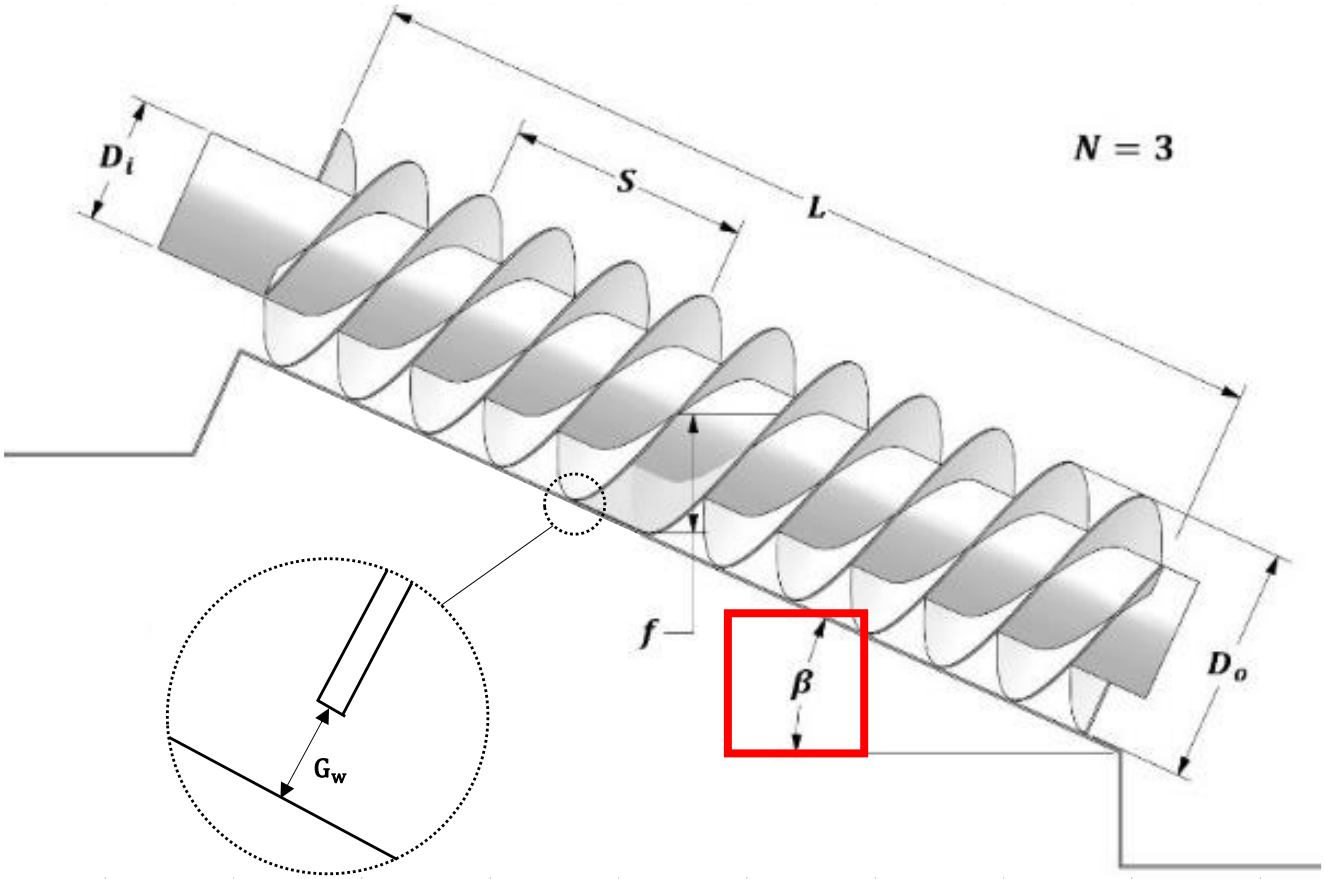


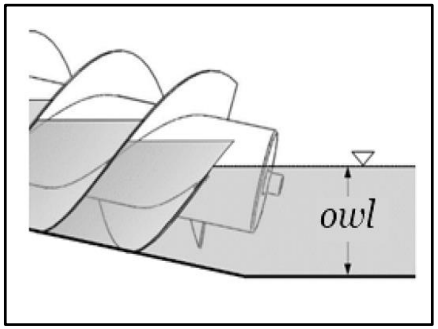
- Three main functional advantages of ASGs include:
  1. Eco-friendliness
  2. Low Cost
  3. Unique Operational Range

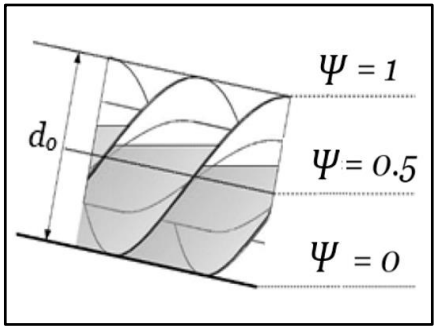


Operational range of different hydropower turbines and generators (Williamson et al., 2014)

ASG Design and Optimization







Varying Inclination with Constant Head

- 16 unique lab-scale screws tested for varying flow rates, rotational speeds, and outlet fill heights
- There are some sets (i.e. 14, 15, 16) that vary only one parameter

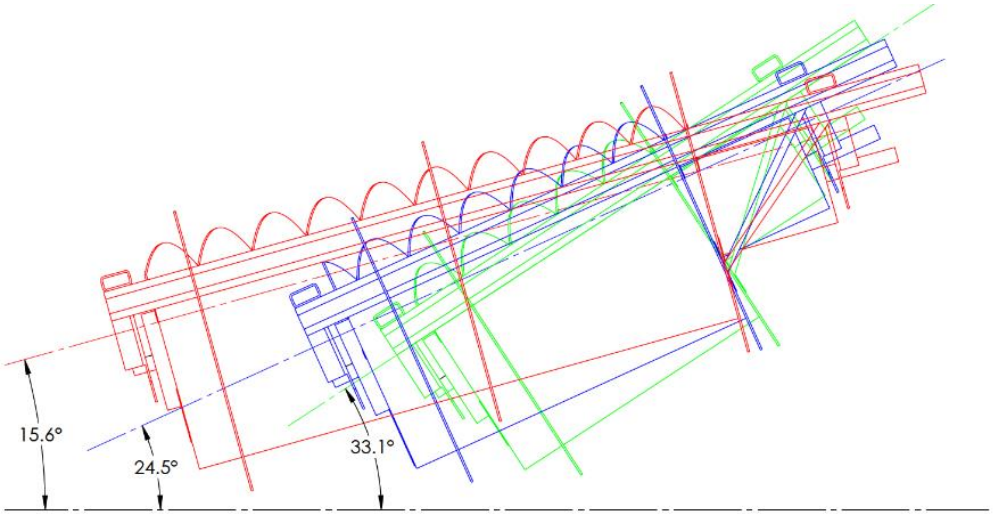
Dimensions of University of Guelph laboratory-scale Archimedes screws.

Screw	OD (cm)	ID (cm)	S (cm)	L (cm)	N	ID/OD	S/L	L/S
#1	31.58	16.83	44.45	121.92	3	0.53	0.36	2.74
#2	31.62	16.83	31.75	121.92	3	0.53	0.26	3.84
#3	31.67	16.83	25.4	121.92	3	0.53	0.21	4.8
#4	31.69	12.7	31.75	121.92	5	0.4	0.26	3.84
#5	31.66	12.7	31.75	121.92	4	0.4	0.26	3.84
#6	31.62	12.7	31.75	121.92	3	0.4	0.26	3.84
#7	31.62	12.7	31.75	63.5	3	0.4	0.5	2
#8	31.57	12.7	31.75	40.64	3	0.4	0.78	1.28
#9	31.64	10.16	31.75	121.92	3	0.32	0.26	3.84
#10	31.61	10.16	44.77	52.07	4	0.32	0.86	1.16
#11	37.8	16.99	30.2	46.89	4	0.44	0.64	1.55
#12	37.69	16.89	30.4	61.39	4	0.44	0.5	2.02
#13	37.69	16.79	30.51	94.69	4	0.44	0.32	3.1
#14	38.2	16.99	38.3	46.61	4	0.44	0.82	1.22
#15	38.1	16.79	38.2	61.7	4	0.44	0.62	1.62
#16	38.61	16.89	38.3	94.89	4	0.44	0.4	2.48

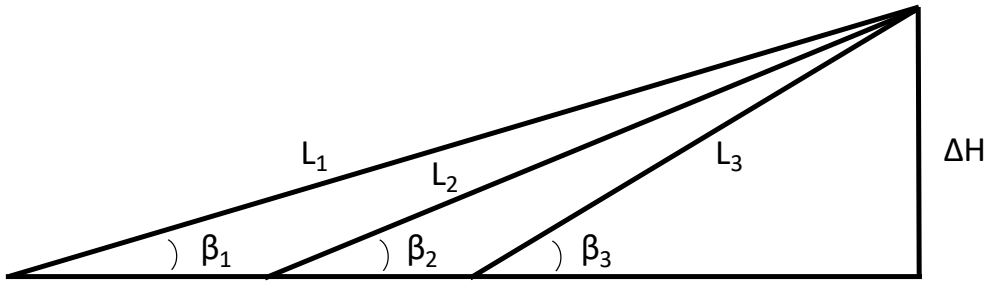
University of Guelph's ASG laboratory setup

Varying Inclination with Constant Head

- Started with 24.5° screw varying the rotational speed and flow rate to find maximum efficiency.
  - The other two inclinations were carried out at corresponding flow rate

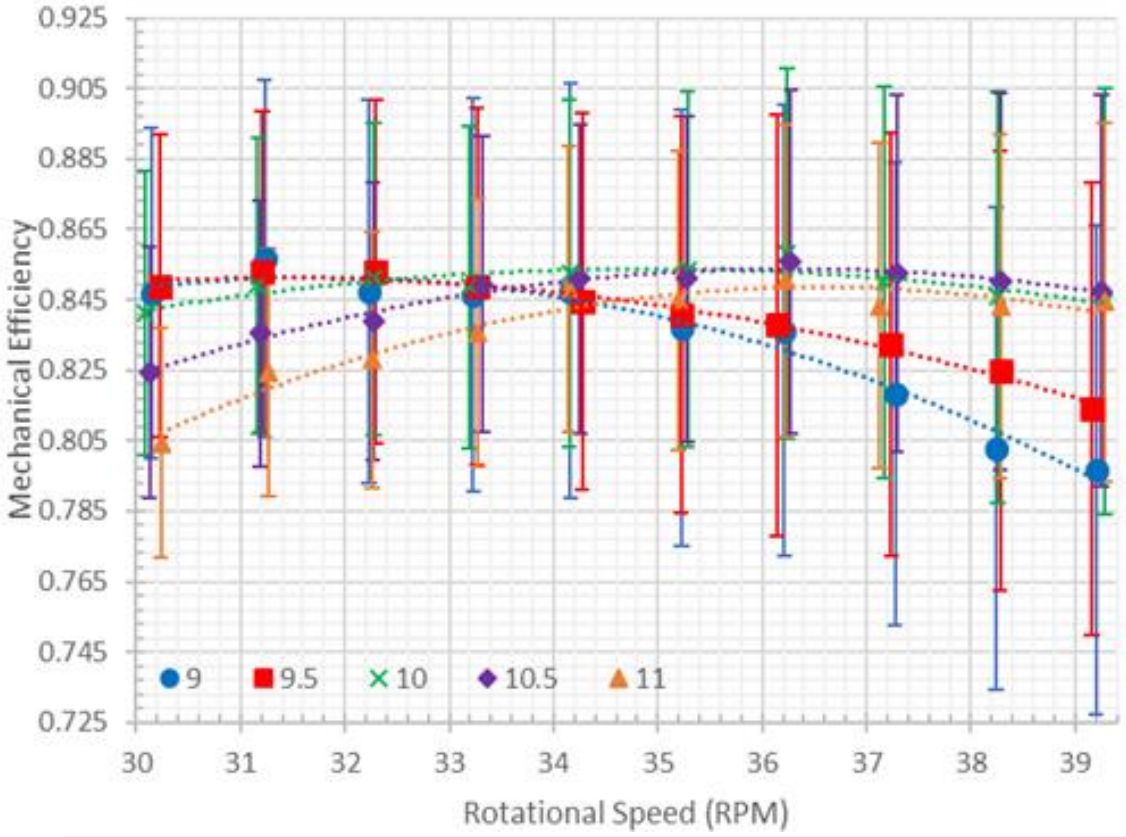


	Symbol	Short Screw	Medium Screw	Long Screw
Number of Blades	N	4	4	4
Inner Diameter (mm)	D_i	168	168	168
Outer Diameter (mm)	D_o	381	381	381
Pitch (mm)	S	381	381	381
Flighted Length (mm)	L	478	617	952
Inclination Angle (deg)	β	33.8	24.5	15.6



Varying Inclination with Constant Head

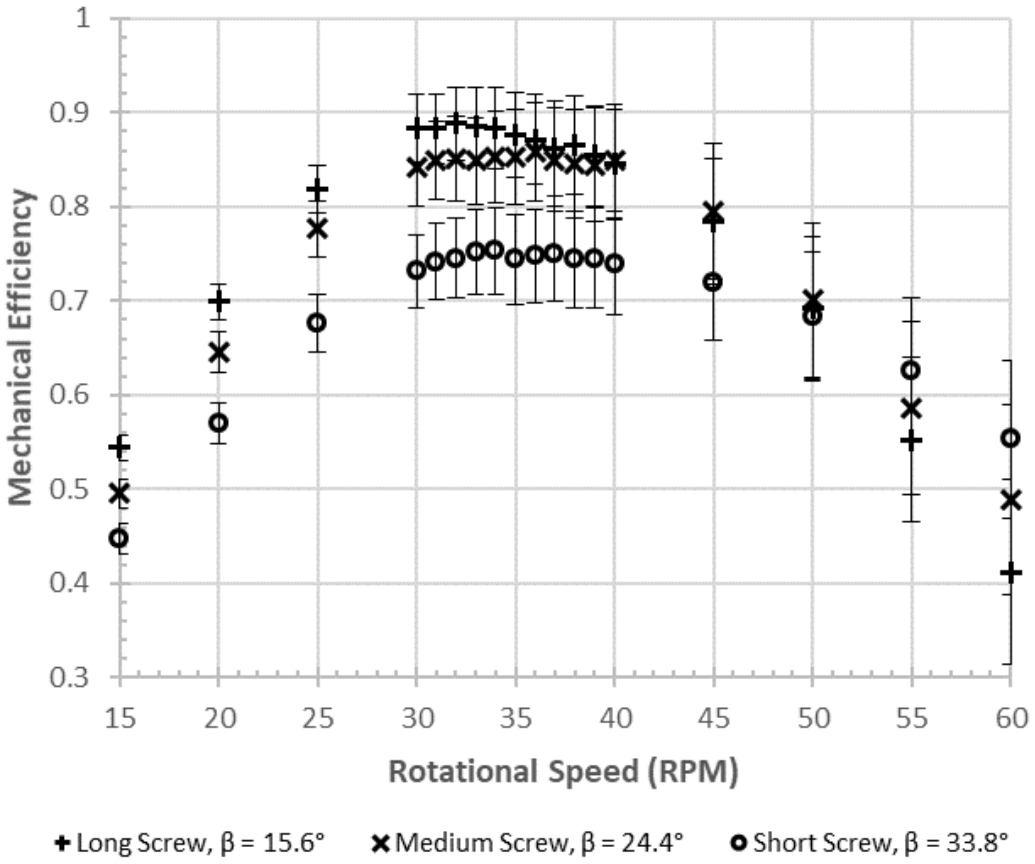
- Flow rate of 10 L/s was selected as optimal flow
  - Most efficient at 36 RPM
- There is an error of about ± 6% efficiency for each point on the plot



Mechanical efficiency of Screw 15, varying rotational speed from 30 to 39 RPM for 5 different flow rates (9, 9.5, 10, 10.5, 11 L/s). The plot has approximate trend lines superimposed to make it easier to visualize the data trends.

Varying Inclination with Constant Head

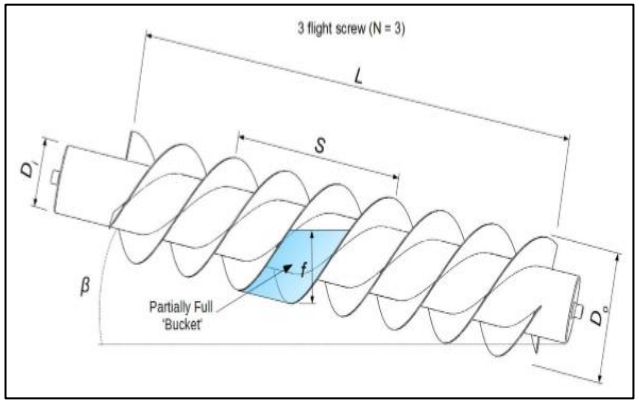
- The lowest inclination angle (15.6°) performed the best throughout most of the rotational speed range
- In high rotational speeds the steepest inclination angle (33.8°), or the shortest screw, performed best

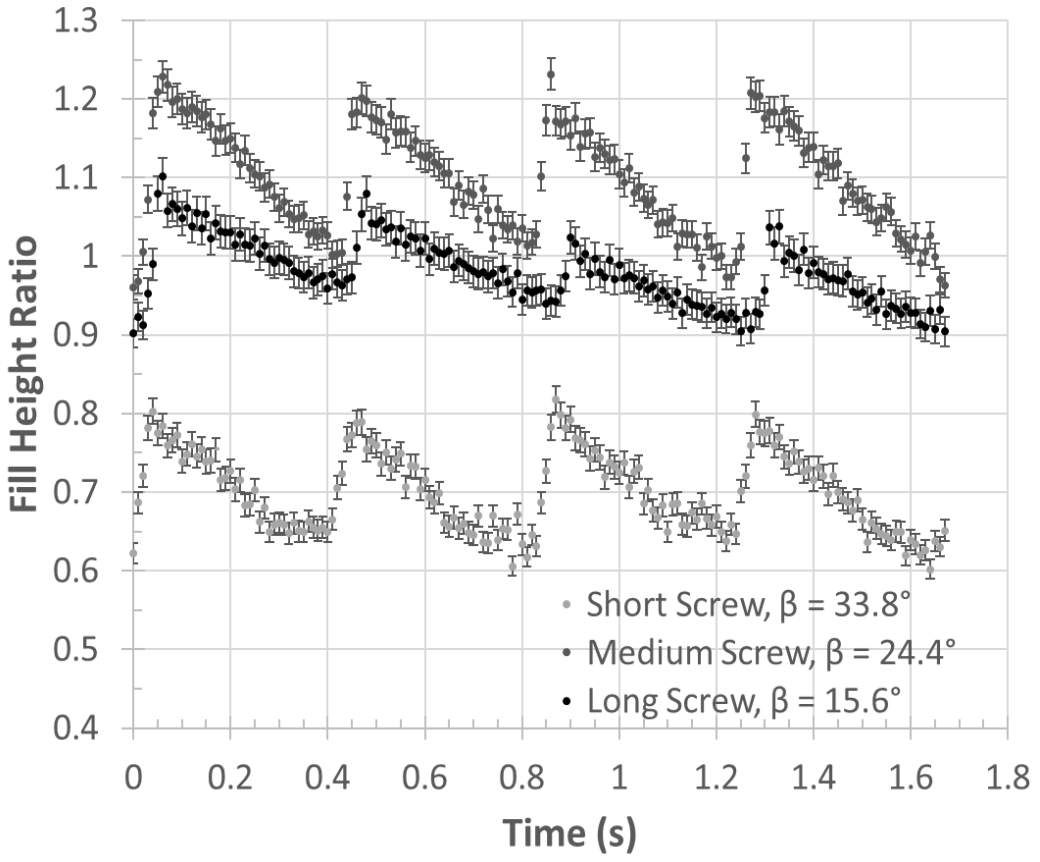


Mechanical efficiency of screw 14, 15, and 16 for varying rotational speeds

Varying Inclination with Constant Head

- There is some overflow in the medium and long screws
- The long screw with the least inclination has most moderate fill height since it has the least head drop between each bucket

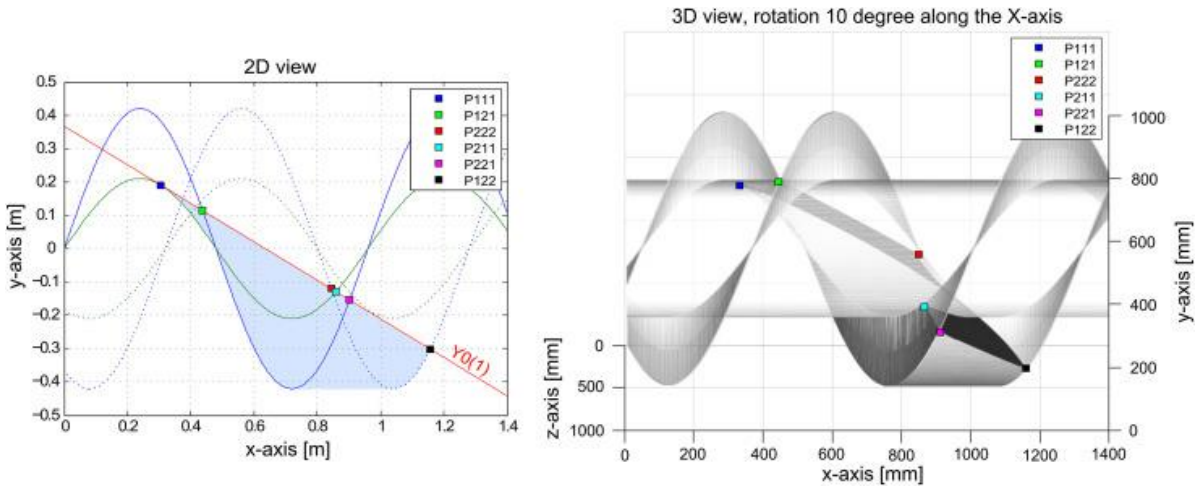




Fill height ratios for screws 14, 15, and 16 over one full screw rotation

Conclusions

- As discussed before, the lower the inclination angle, the more volume of water can fit within the bucket
  - Allowing more of the water's energy to be converted into mechanical power
- On the small scale, the most power was produced by the longest screw making it the most **mechanically efficient**
  - This might be the case when scaling up to a full-sized ASG installation, but the cost for construction of a longer system will make it less **economically efficient**.

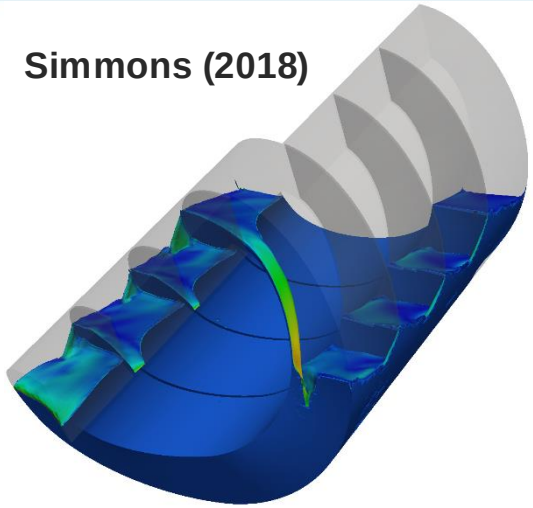


Archimedes screw bucket geometry (Rohmer et al. 2016)

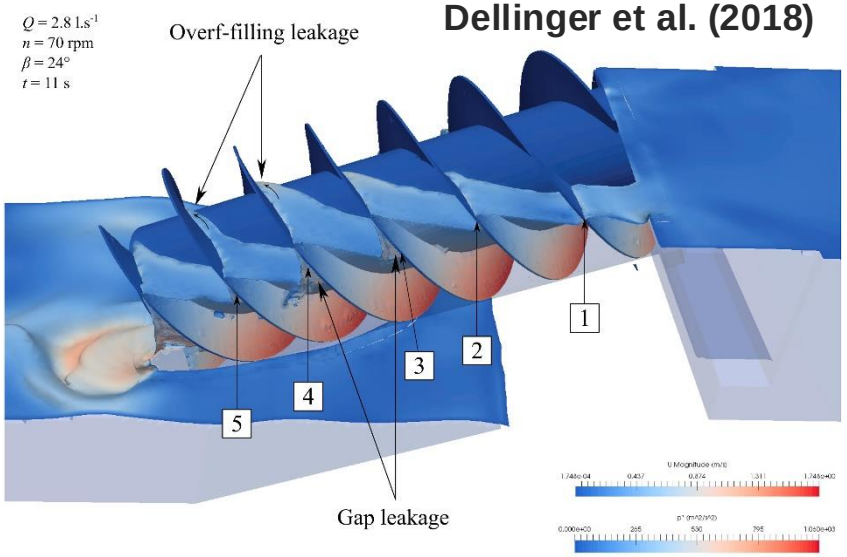
Current and Future Work

- We will be extending out experimental data with a full-scale CFD model of our laboratory experiment
  - Using the validated CFD models presented in Dellinger et al. (2018) and Simmons (2018)
- This will help to draw conclusions based on different geometries that would be expensive to machine as well as extending the data to cover full-scale installations.

Simmons (2018)



Dellinger et al. (2018)



Thank you!

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