Dynamic overflow leakage in Archimedes screw generators

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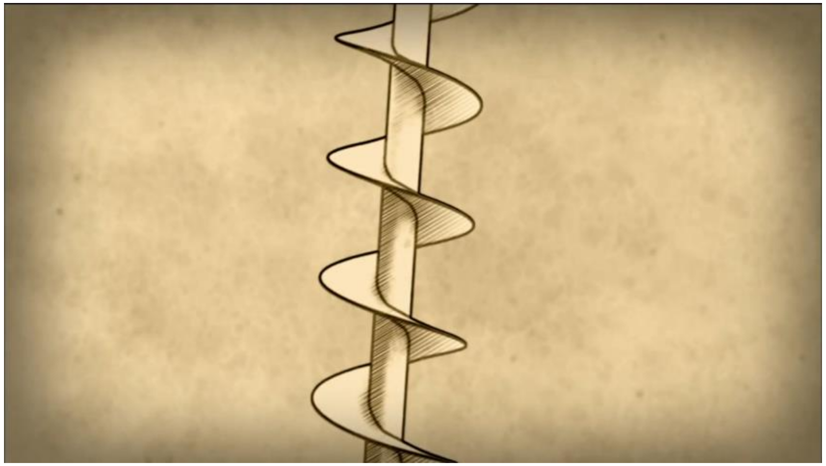
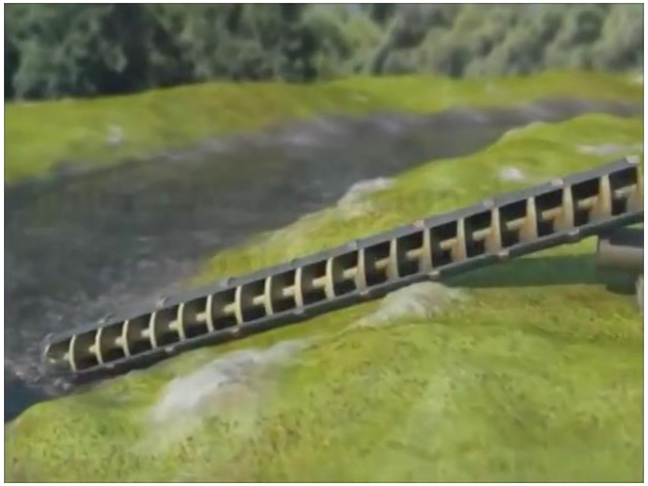
1. Archimedes screws

- Archimedes screws are an ancient pumping technology
- Named after Archimedes of Syracuse (~287-212 BCE)
- Evidence suggests it was used during reign of King Sennacherib (704-681 BCE) of the Neo-Assyrian Empire
- Trap water between blades as screw rotates due to an applied torque
- Water translates along axis of rotation



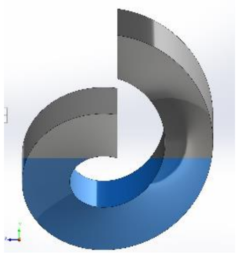
PBS (2014), *Secrets of the dead: Archimedes' screw and the Hanging Gardens of Babylon* [https://www.youtube.com/watch?v=NhNEB_mWvBw&ab_channel=PBS].



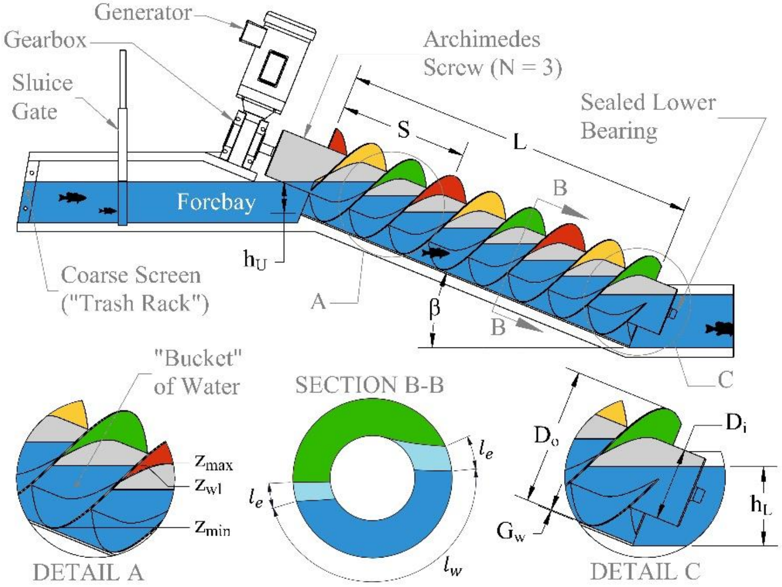
Adriana Tub (2016), *Tornillo de arquimedes* [https://www.youtube.com/watch?v=A_mZ6ekbJtw&ab_channel=AdrianaTub].

2. Archimedes screw generators

- Generators operate in reverse to convert mainly hydrostatic pressure into mechanical torque
- Inflow at top fills between blades
  - Termed a “bucket”

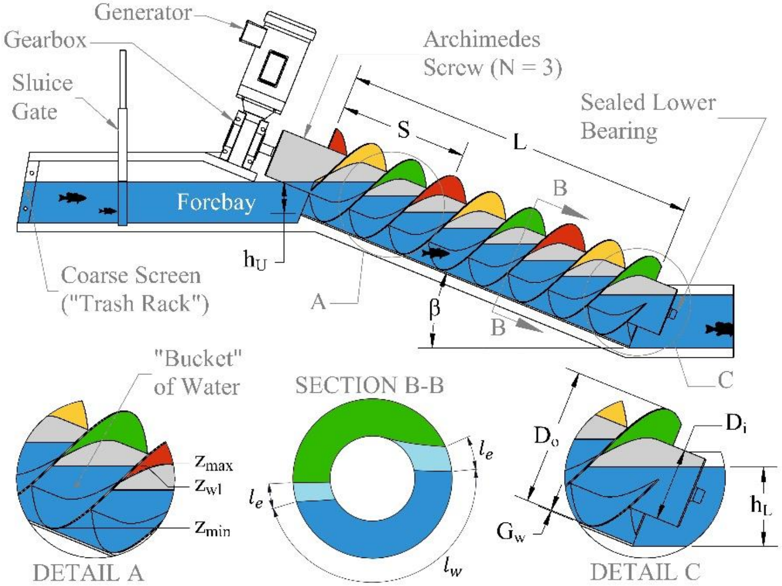


- Water translates down screw and trough and exits into outlet reservoir
- Mechanical torque converted to electrical power by a generator



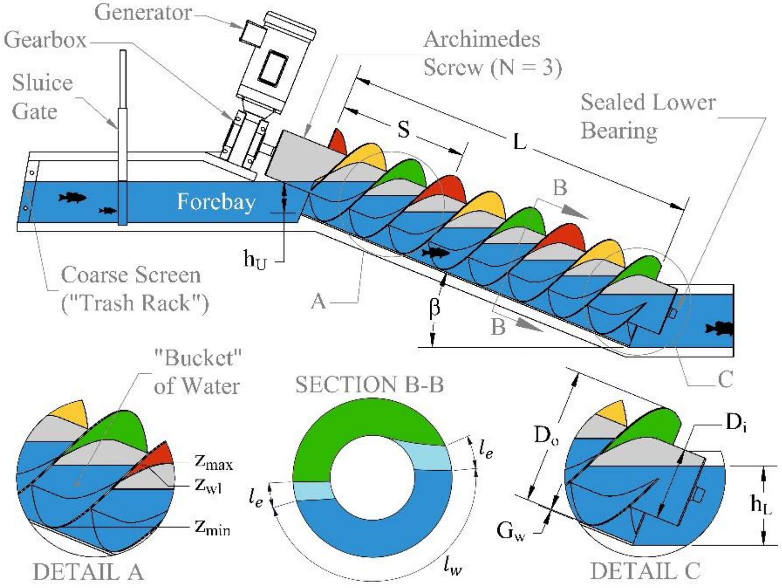
2. Archimedes screw generators

- Archimedes screw generators (ASGs) usually have river-to-wire efficiencies of 75% (or greater in some cases)
- Power production is largely due to hydrostatic pressure in water (head drop)
- Power losses are largely due to both static and dynamic phenomenon
  - Friction loss
    - Hydraulic
    - Mechanical
  - Entrance losses at inlet and outlet
  - Non-optimal lower water level
  - Leakage losses
    - Gap leakage
    - **Overflow leakage (focus of this study)**



3. Types of overflow leakage

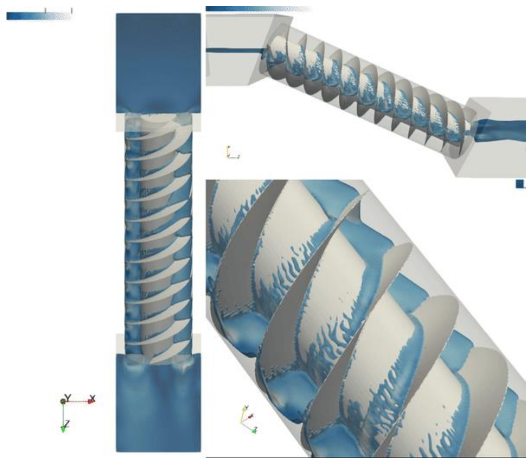
- Overflow leakage occurs in two forms:
  - Static overflow leakage
  - Dynamic overflow leakage



- Static overflow is when the water level of each bucket (z_{wl}) exceeds its maximum fill point (z_{max}) and spills into the successive bucket

- Commonly use the fill height ratio to define this:

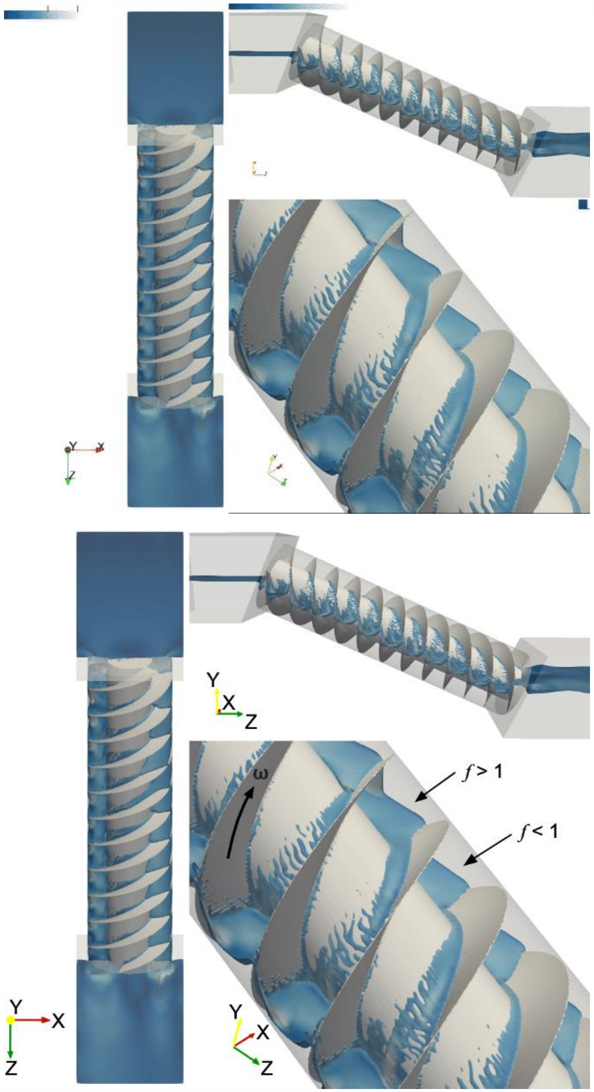
$$f = \frac{z_{wl} - z_{max}}{z_{max} - z_{min}}$$



- When $f > 1$, static overflow occurs

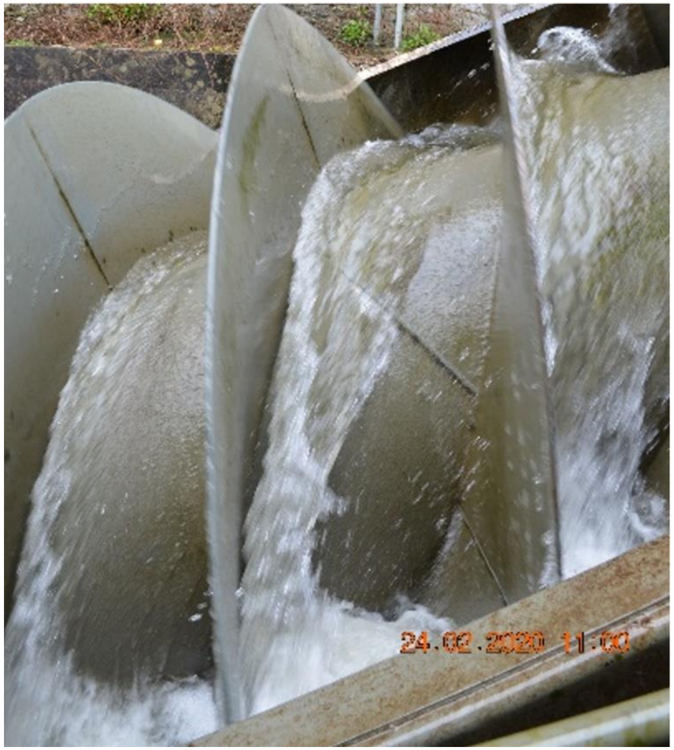
3. Types of overflow leakage

- Dynamic overflow is a thin-film phenomenon due to two-phase boundary layer flow
- It operates in the opposite direction of static overflow leakage due to direction of screw rotation
- We noticed it varied with surface roughness and was visible in some real-world ASG powerplants



3. Types of overflow leakage

Static Overflow



Buckfast Abbey Powerplant

Buckfastleigh, Devon, UK

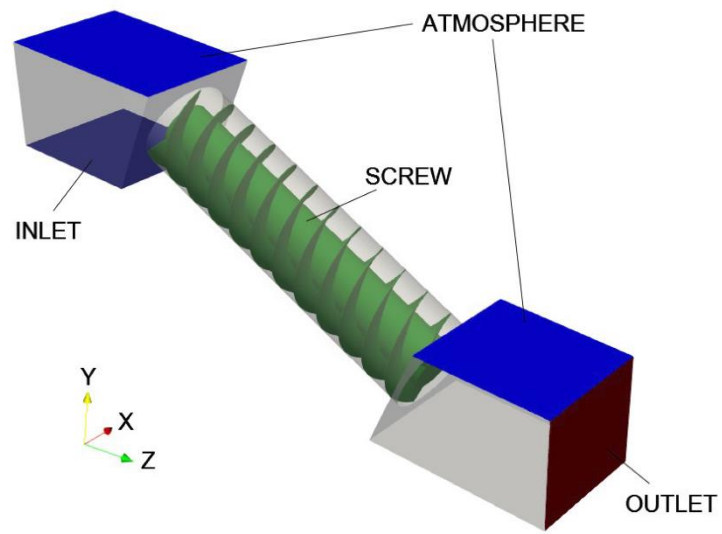
Dynamic Overflow

Windsor Castle Powerplant

Romney Lock, Windsor and Maidenhead, UK

4. Methods

- It would be extremely difficult to accurately measure dynamic overflow
- We use computational fluid dynamics (CFD) to simulate an operating screw and measure overflow
  - **Software:** OpenFOAM 4.0, OpenFOAM foundation, 2016
  - **Meshing:** Dynamic mesh to simulate screw rotation
  - **Governing equations:** Reynolds-averaged Navier-Stokes (RANS) equation with the Volume of Fluid (VoF) method to account for two-phase flow (water and air)
  - **Turbulent closure:** Menter's Shear Stress Transport (k-ω SST)

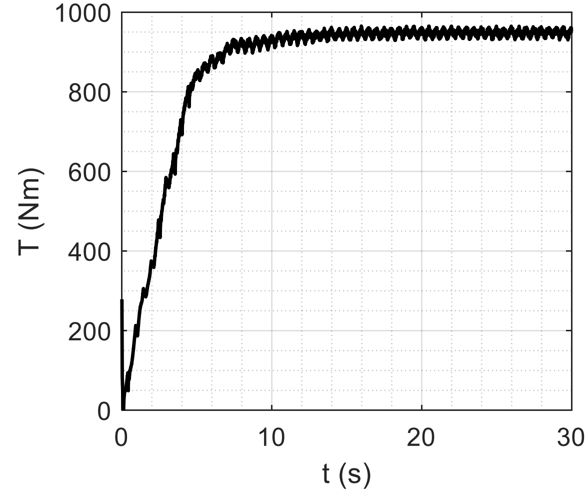


5. Results

5.1. CFD model evaluation

- CFD models were simulated to convergence
  - Occurs at a quasi-steady state condition where torque oscillations are stable

- Simulations were carried out at the operating conditions of lab experiments and real-world data that we had collected



Archimedes Screw Laboratory
University of Guelph

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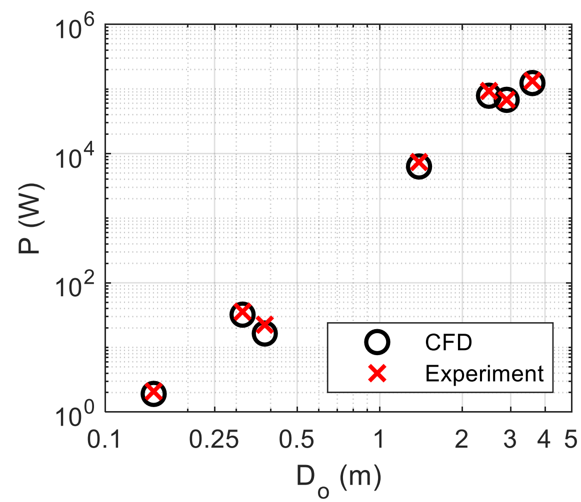
Buckfast, UK

Ruswarp, UK

Ferrara, Italy

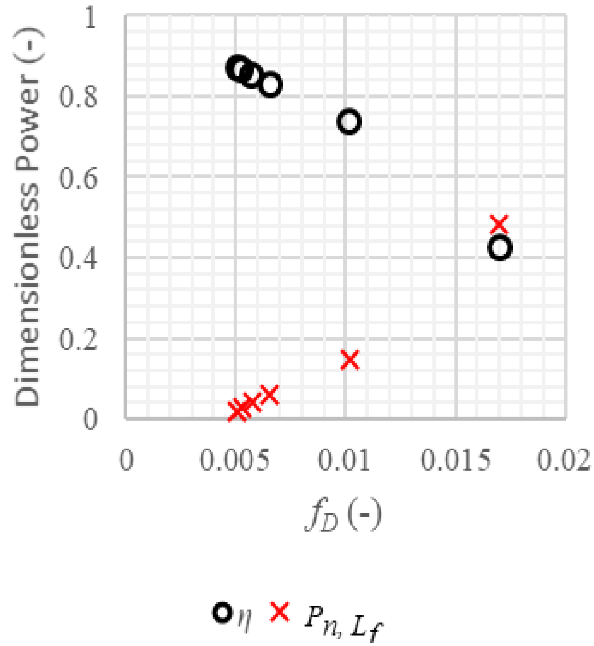


5.2. Dynamically impacted losses

- CFD was then used to observe the effects of surface roughness on power production and dynamic overflow

- Roughness values were varied as follows:

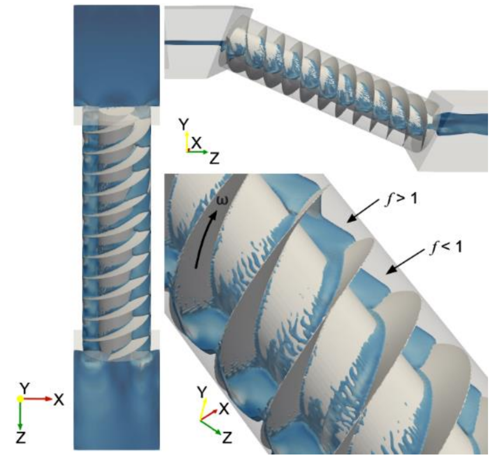
Surface	Gauckler-Manning Coefficient n (s / m$^{1/3}$)	Roughness Height z_o (mm)	Darcy-Weisbach Friction Factor f_D (-)
Smooth	0	0	0.00507
Glass	0.010	0.3	0.00529
Smooth Steel	0.012	1.0	0.00574
Painted Steel	0.014	2.4	0.00655
Algae on Steel	0.018	11.4	0.0102
Corrugated Steel	0.022	37.0	0.0170

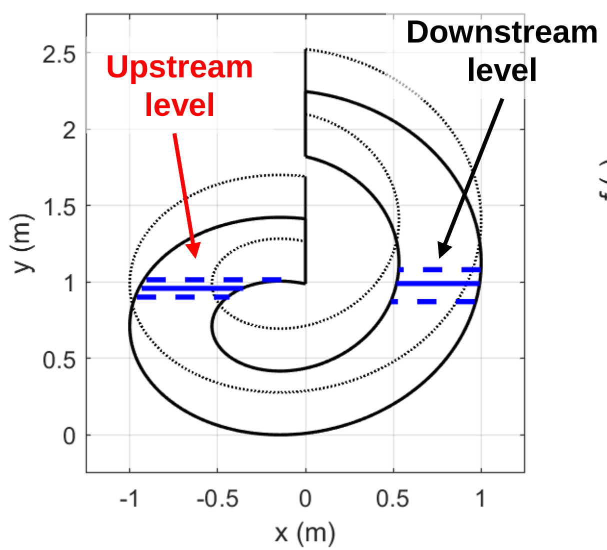


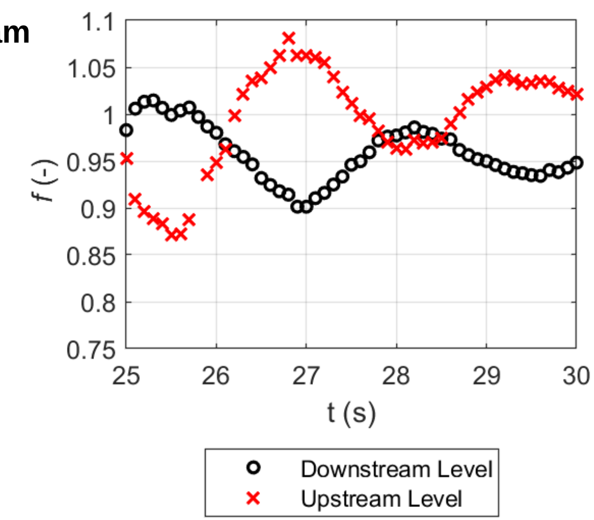
5. Results

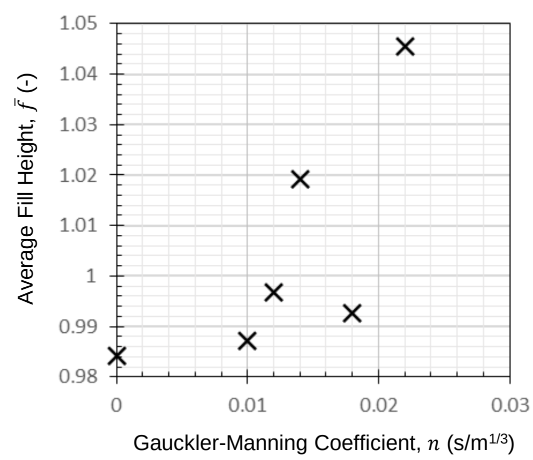
5.3. Overflow leakage

- It was theorized that surface roughness would effect both static and dynamic overflow
- Static overflow varies along screw length during operation (termed the "sloshing effect")
- Water level oscillation ("sloshing") magnitude increased slightly with surface roughness, but not significantly





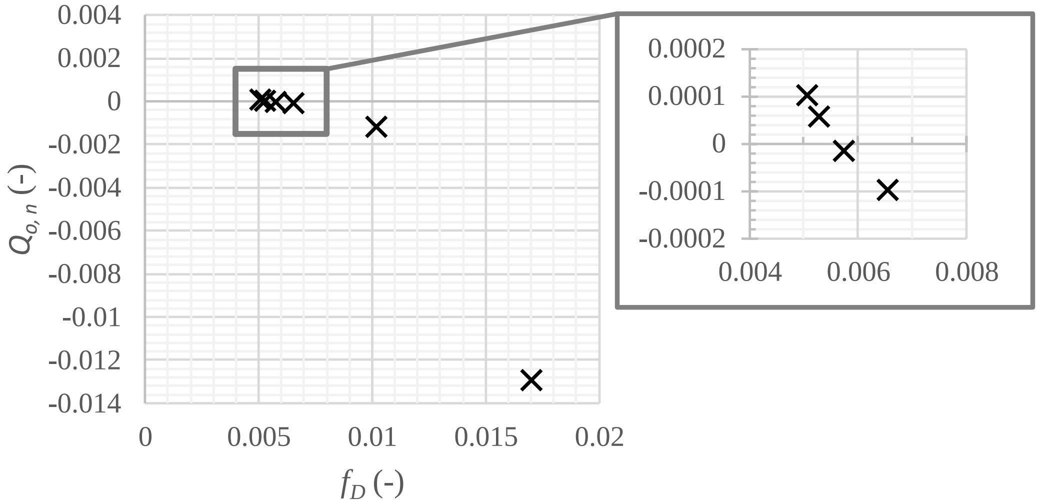




5. Results

5.3. Overflow leakage

- The magnitude of dynamic overflow leakage increased with surface roughness significantly
- Water film on blades increased as blade roughness increased, producing more "negative" overflow leakage
- This may seem very small, but two ASG powerplant owner/operators reported to have upwards of 10% efficiency improvements after cleaning their screws



6. Conclusions

- ASG powerplants may be designed with optimization software to produce power most effectively
  - Optimization software requires accurate performance predicting algorithms
- Dynamic overflow leakage is not included in any current performance prediction models in the literature
- Modelling dynamic overflow is underway at the University of Guelph
- Its addition to optimization software will help improve plant design
  - Optimizing screw materials based on cost of surface finish
  - Generating cleaning schedules to minimize cost of cleaning/downtime and maximizing efficiency improvements

Overview

Thank you for your time!

Acknowledgements

- Tony Bouk and Brian Weber at Greenbug Energy Inc. (Canada)
- David Mann and Adrian Clayton of Mann Power Consulting Ltd. (UK)
- Chris Elliot of On Stream Energy Ltd. (UK)
- David DeChambeau of Southeast Power Engineering Ltd. (UK)
- Mike Ford of Esk Energy (Yorkshire) Ltd. (UK)
- Mohamed A. Samaha of RIT Dubai (UAE)
- Nicola Fergnani of HydroSmart Srl (Italy)
- Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD)