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Prediction of Minor Loss Coefficient at Suction Inlet of a Cutter Suction Dredge

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OUTLINE

- Research Objectives
- Experimental Setup
- Data Collection
- Results
- Conclusions
- Recommendations

RESEARCH OBJECTIVES

Primary:

- Quantify and predict a fixed screen's minor loss coefficient (*k*) while changing:

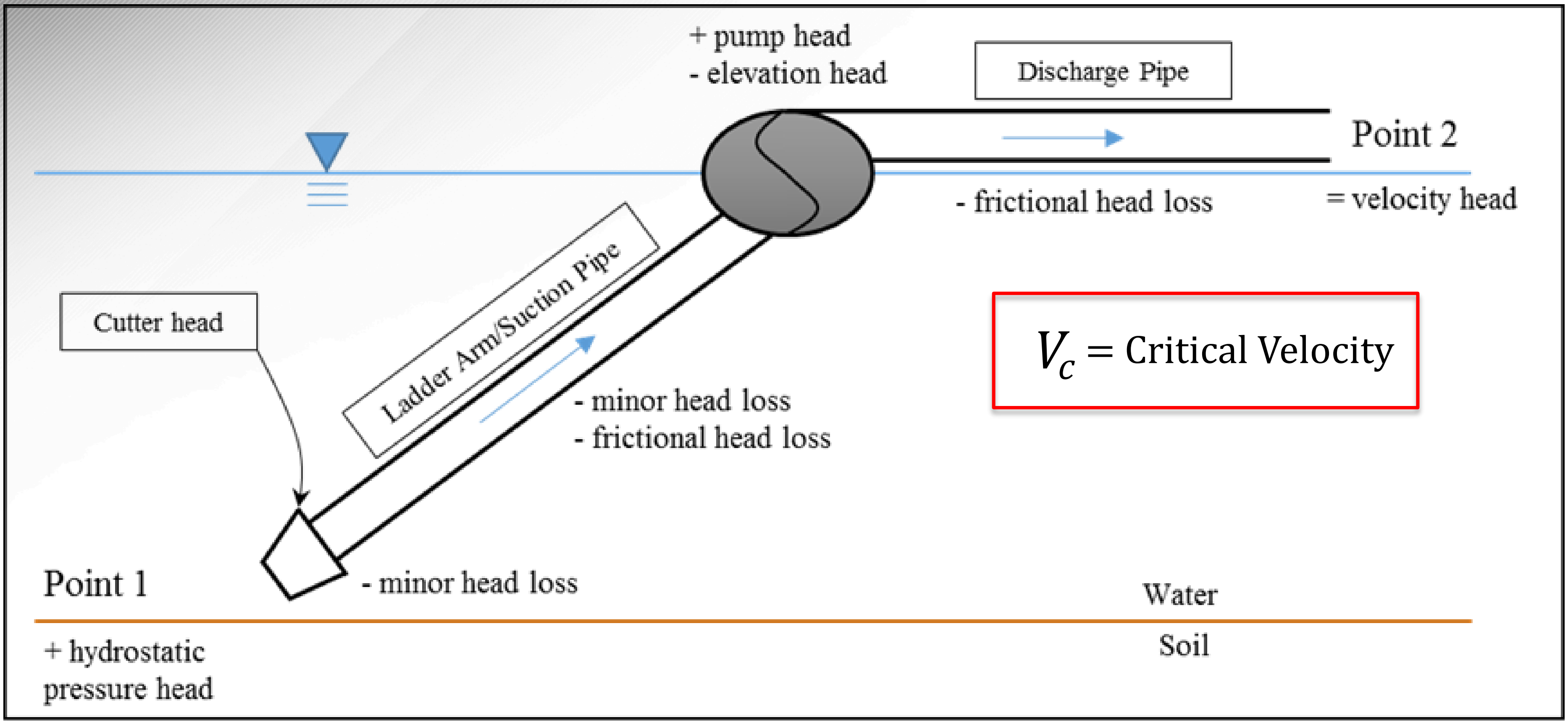
  - Cutter head rotational speed, Ω *[RPM]*
  - Ladder arm swing speed, V_L *[in/s]*
  - Screen Opening Percentage, β *[Area of Openings/Area of Suction Mouth]*

- Can *k* be expressed as: $k = f(\Omega, \beta, V_L)$?

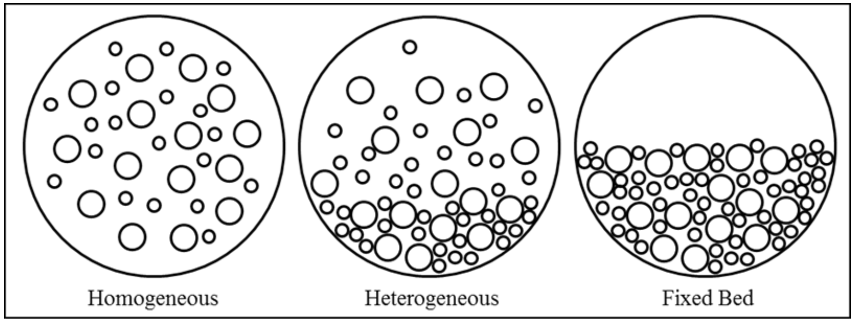
Secondary:

- Effect of screen opening shape
- Evaluate $SG = f(\Omega, V_L)$

SLURRY FLOW
Cutter Suction Dredge



$$\frac{P_1}{\gamma}+\frac{{V_1}^2}{2g}+z_1+h_p=\frac{P_2}{\gamma}+\frac{{V_2}^2}{2g}+z_2+h_L$$



SLURRY FLOW

Cutter Suction Dredge

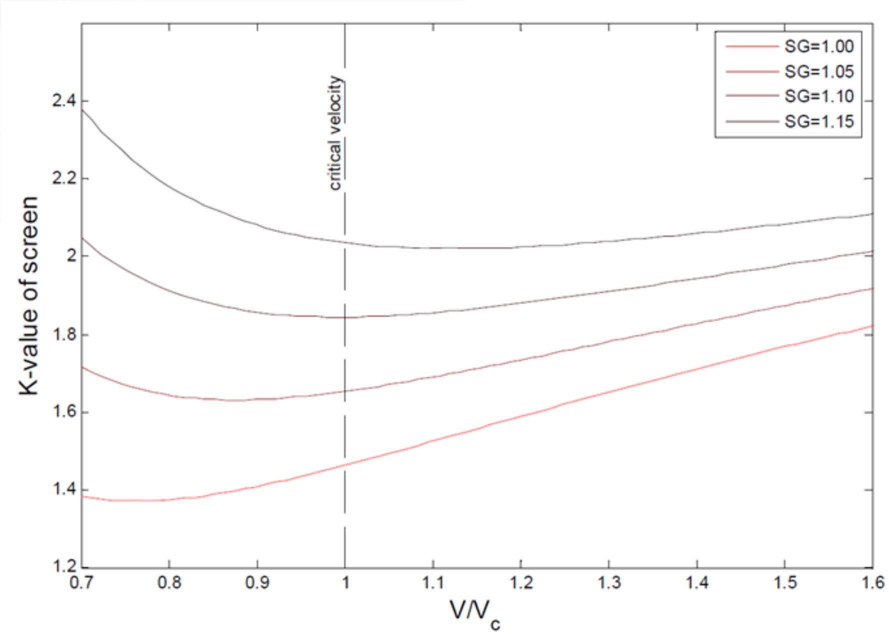
Influence of Flow Rate and Specific Gravity

- Low flow rate:
  - Cutter head-dominant flow field
  - Significant spillage occurs (Steinbusch, et al., 1999)
    - 5 to 40% of total dredged material (Dekker, et al., 2003)
  - Low production
  - ↓ *k* (Girani, 2014)
- High flow rate:
  - Suction-dominant flow field
  - Less spillage (↑ SG)
  - Increased production (Henriksen, 2009)
  - ↑ *k*

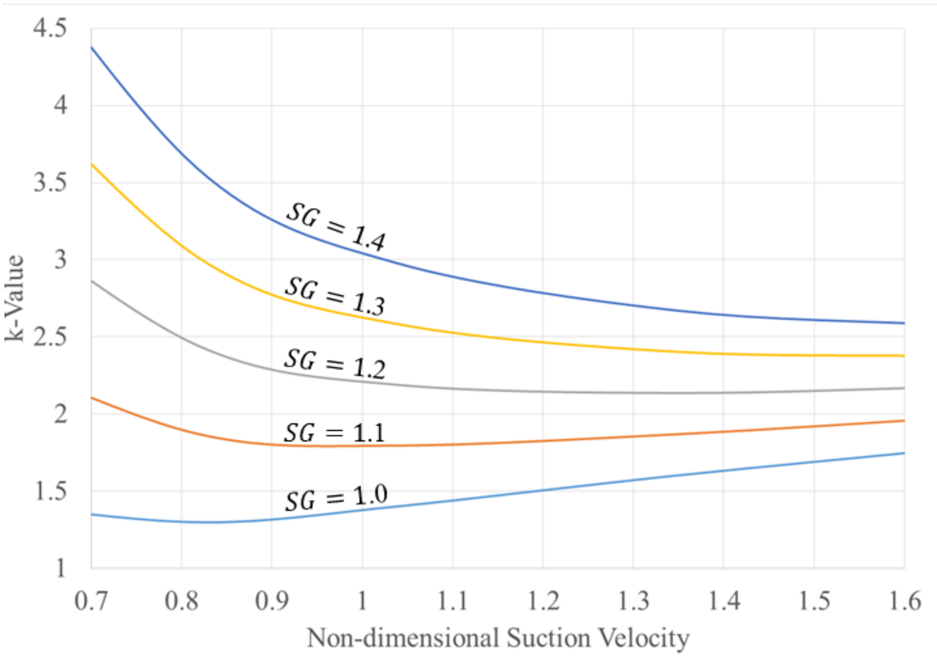
LITERATURE REVIEW

Influence of Flow Rate and Specific Gravity

- Specific Gravity (SG) and Minor Loss Coefficient (k)



Girani (2014)



LITERATURE REVIEW

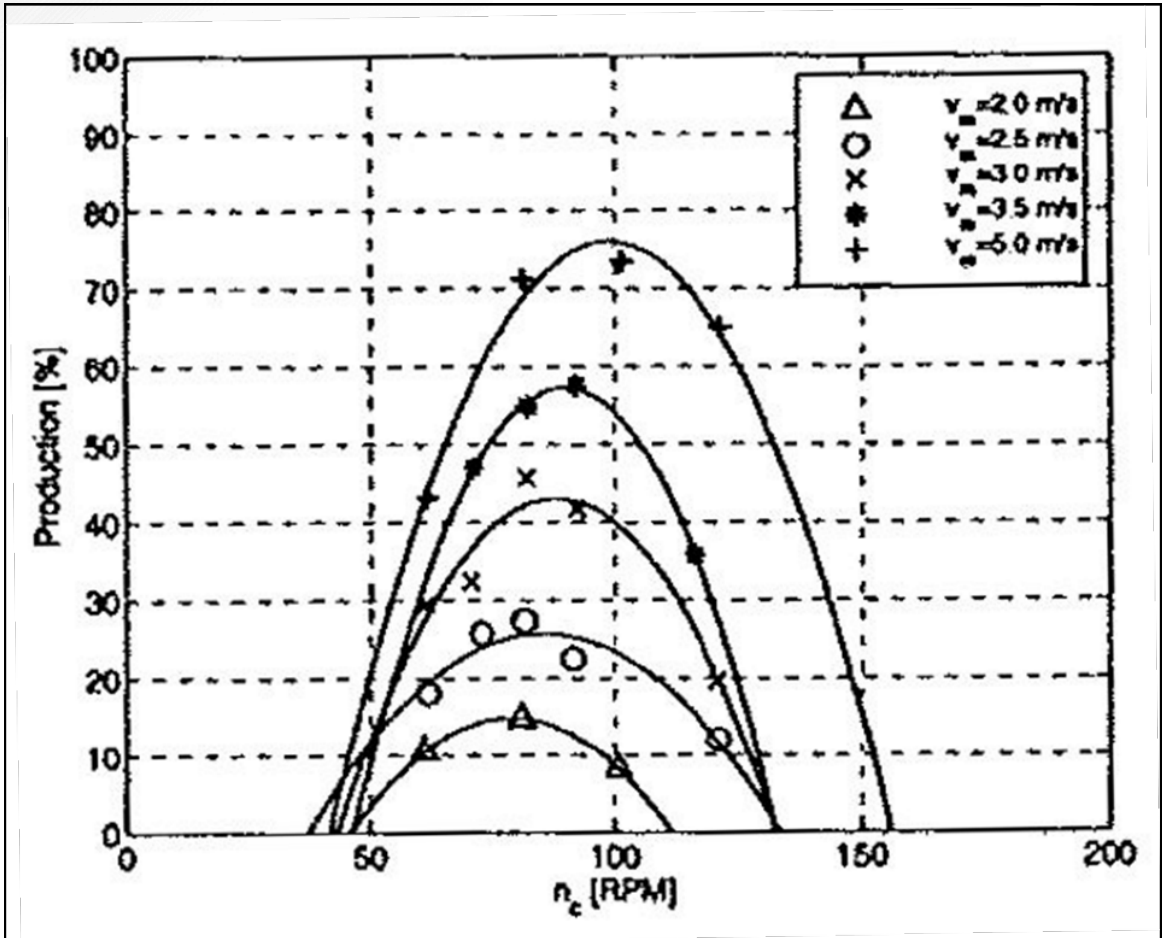
Influence of Cutter Head Rotational Speed (Ω)

- High Cutter Head Speeds:
  - Greater re-suspended sediment (Henriksen, et al., 2011)
  - Greater spillage (Hayes, et al., 2000)
  - Centrifugal force > (Gravitational Force + Drag Force) (den Burger, et al., 1999)
  - Reduced production

- Low Cutter Head Speed:
  - (Gravitational Force + Drag Force) > Centrifugal force (den Burger, et al., 1999)
  - Poor mixing (den Burger, et al., 1999)
  - Reduced production

LITERATURE REVIEW

Influence of Cutter Head Rotational Speed (Ω)

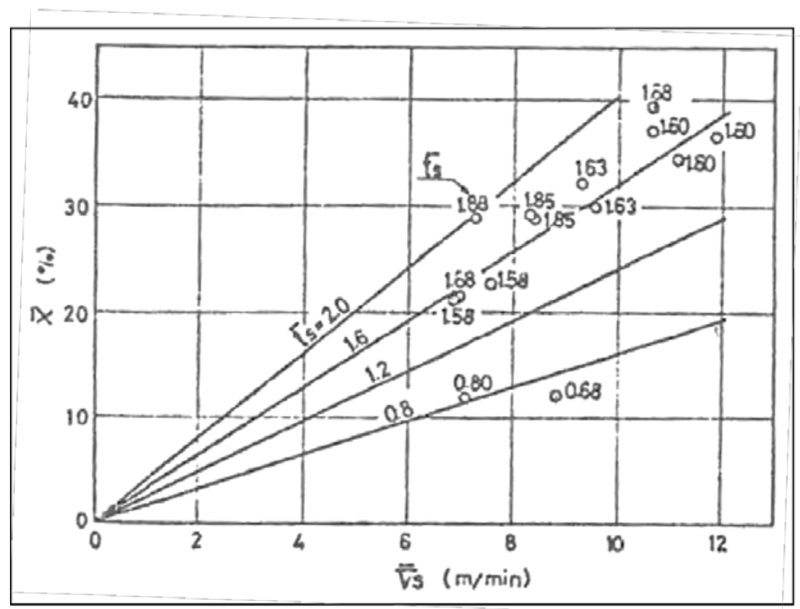


den Burger, et al., 1999

Influence of Ladder Arm Swing Speed (V_L)

- Prediction Models (Hayes, et al., 2000):
  - Dimensional Model: Spillage ↓ when V_L ↑
  - Non-dimensional model: Spillage ↑ when V_L ↑

- Experiments (Yagi, et al., 1975):
  - Mud Content in Pipeline ↑ when V_L ↑



MODEL SCALING

Operating Parameter	Prototype	Haynes Lab Model Dredge	Model to Prototype Ratio
Cutter Head Rotational Speed	30 RPM	15 to 45 RPM	1:2 to 1:$^{2}/_{3}$
Cutter Head Diameter	60 in (152 cm)	16 in (40.6 cm)	~1:4
Cutting Thickness	30 in (76 cm)	10 in (25 cm)	1:3
Water Depth	40 ft (12.2 m)	8 ft (2.44 m)	1:5
Grain Size (d_{50})	0.00164 ft (0.5 mm)	0.00090 ft (0.275 mm)	~1:2
Grain Settling Velocity*	0.207 ft/s (63 mm/s)	0.108 ft/s (33 mm/s)	~1:2
Discharge Pipe Diameter	30 in (76 cm)	3 in (0.076 m)	1:10
Ladder Arm Swing Speed	12 in/s (30 cm/s)	1.0 to 3.0 in/s (2.5 to 7.6 cm/s)	1:12 to 1:4
Flow Rate	30,000 GPM (113,550 l/min)	250 to 400 GPM (946 to 1514 l/min)	1:5 to 1:4

*calculated using Schiller (1992) equation

MODEL SCALING

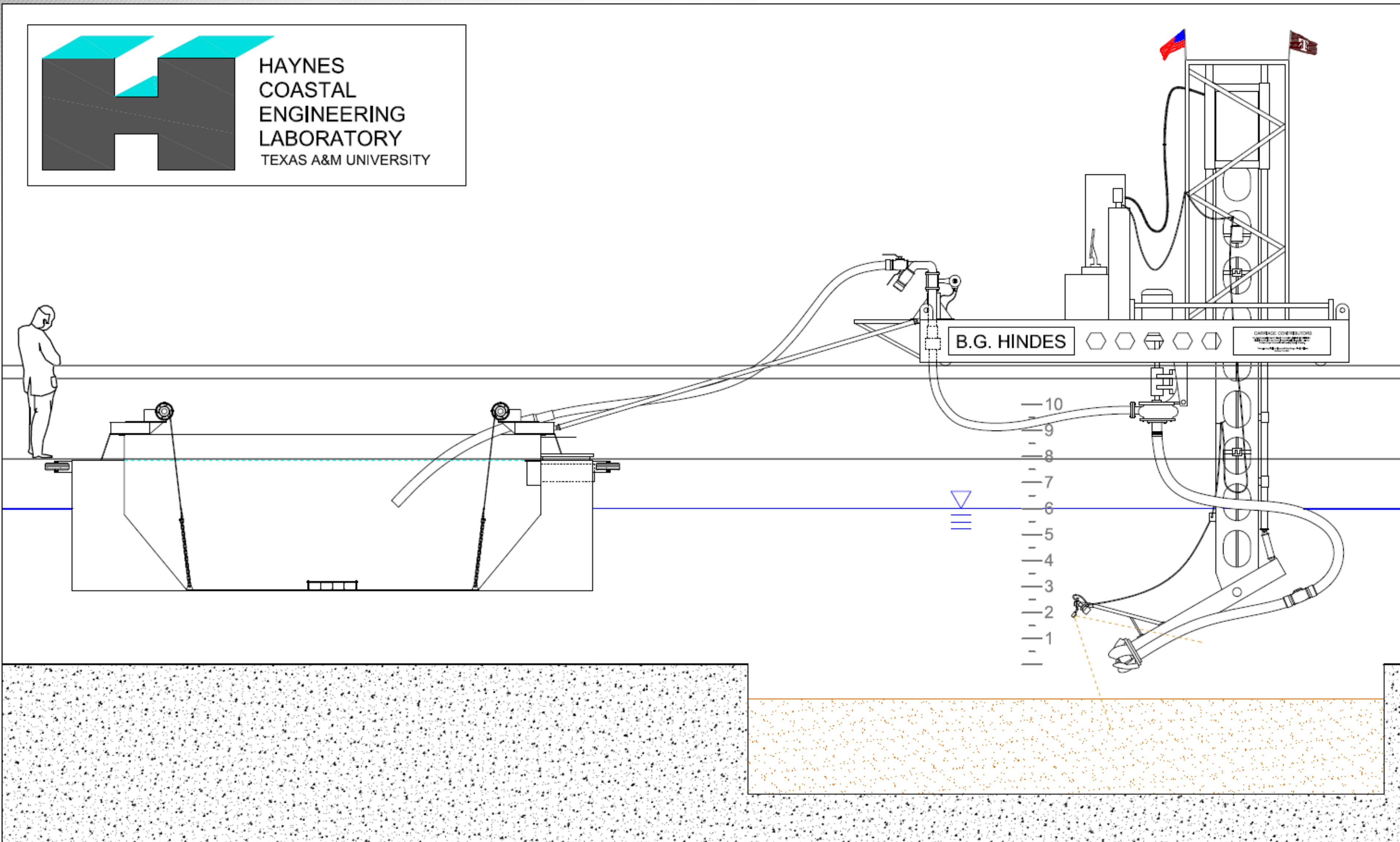
Hydraulic Scaling
(sediment pick-up behavior)

Glover (2002)

Kinematic Scaling
(Froude Number)

Parameter	Scaling Method			Chosen Test Parameters
	Hydraulic	Kinematic	Geometric (1:10)	
Q_{model} (GPM)	1117	1102	30	250 to 400
Ω_{model} (rpm)	21	58	30	15 to 45
$(V_L)_{model}$ (in/s)	3.2	6.2	1.2	1.0 to 3.0

TEST SETUP


HAYNES
COASTAL
ENGINEERING
LABORATORY
TEXAS A&M UNIVERSITY
B.G. HINDES
10
9
8
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6
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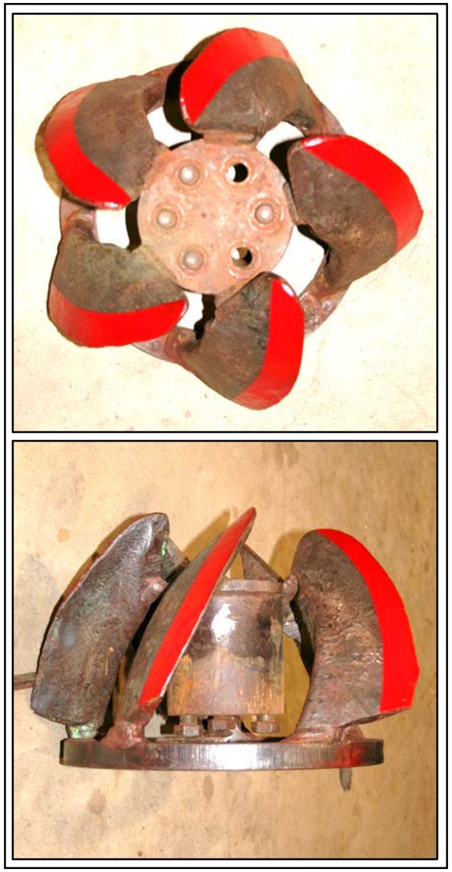
4
3
2
1

TEST SETUP

Suction Inlet

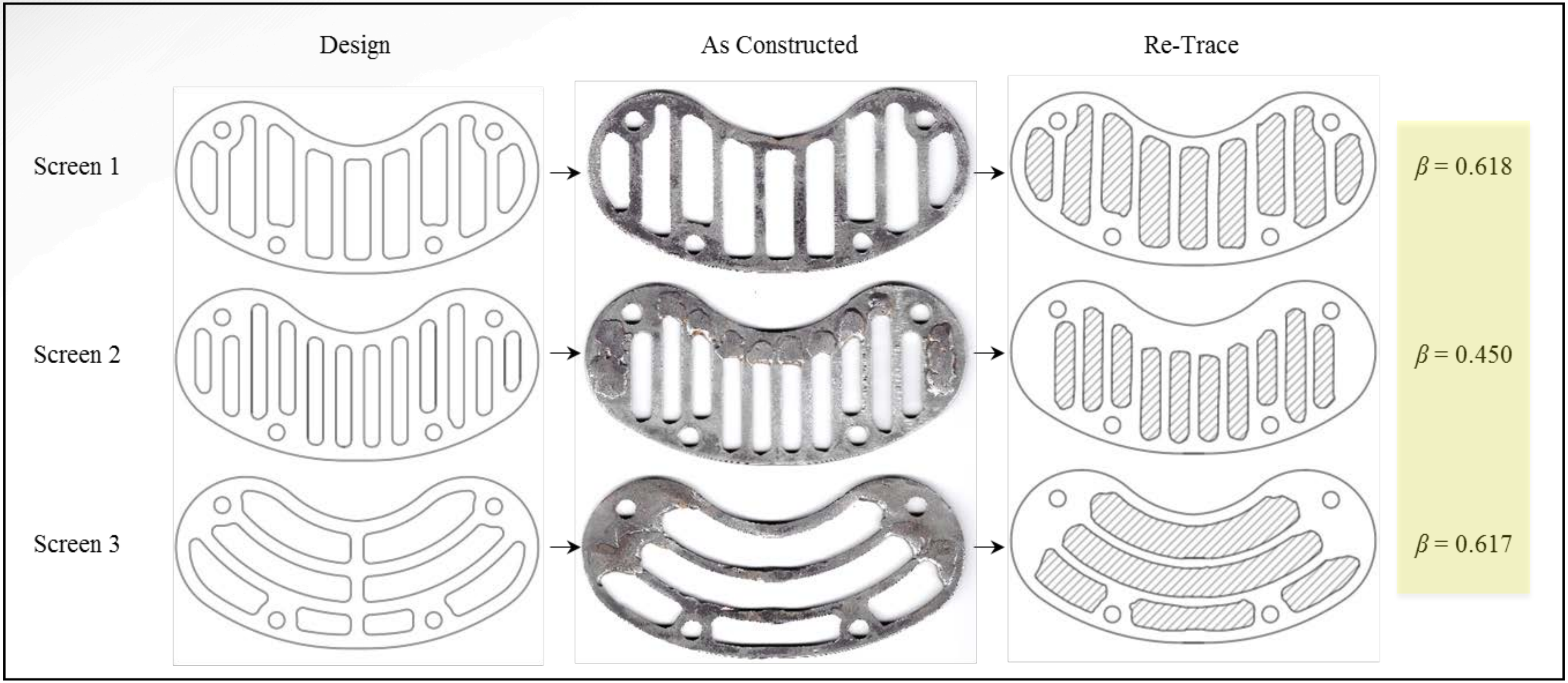
Total Opening Area = 14.0 in^2



Diameter = 16 in

TEST SETUP

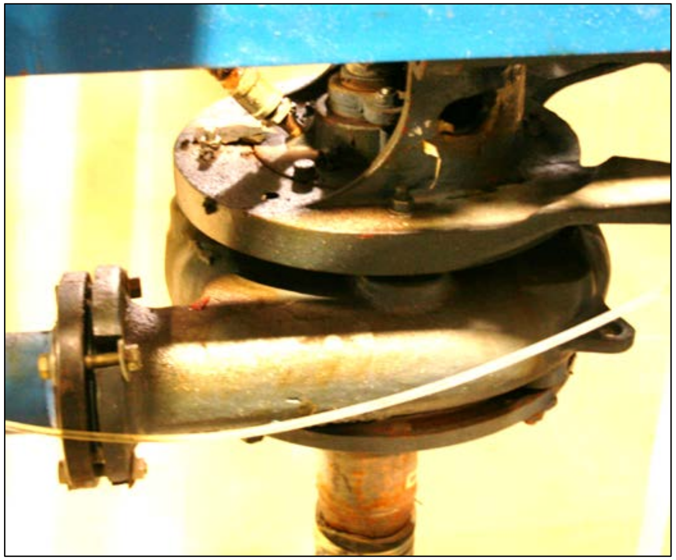
Screens



TEST SETUP

Centrifugal Pump

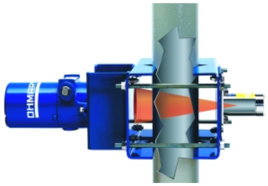
- Manually controlled
- h_p = 20 hp
- Max flow rate = 600 GPM
- Vane diameter = 12.2 in
- P_s and P_d measured
- 3” discharge hose



TEST SETUP

Sensors

- Ohmart GEN2000® nuclear density gauge



Ohmart (2014)

- Krohne IFC 090K electromagnetic flow meter

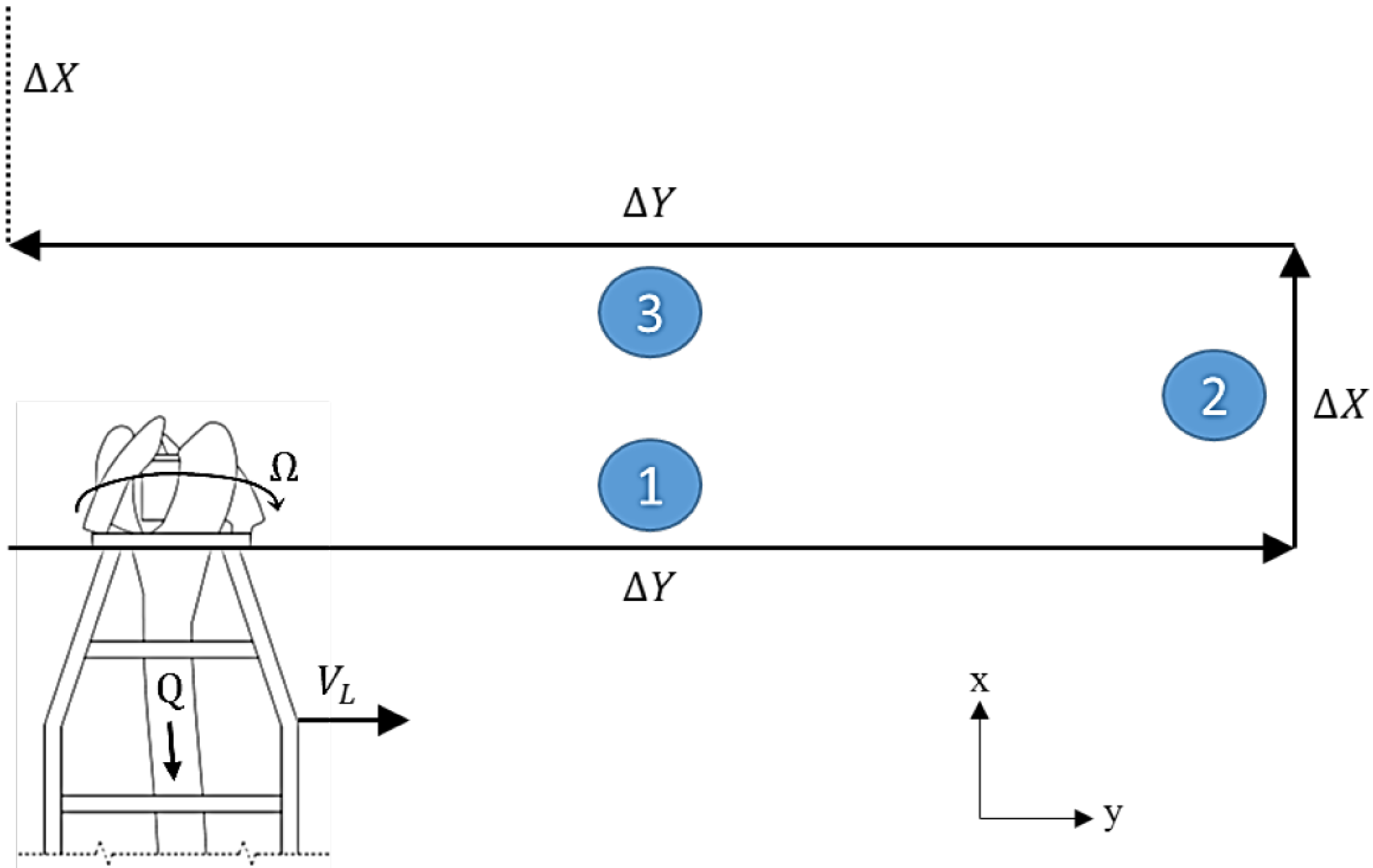
Krohne (1997)

- Rosemount 1511AP pressure transmitter

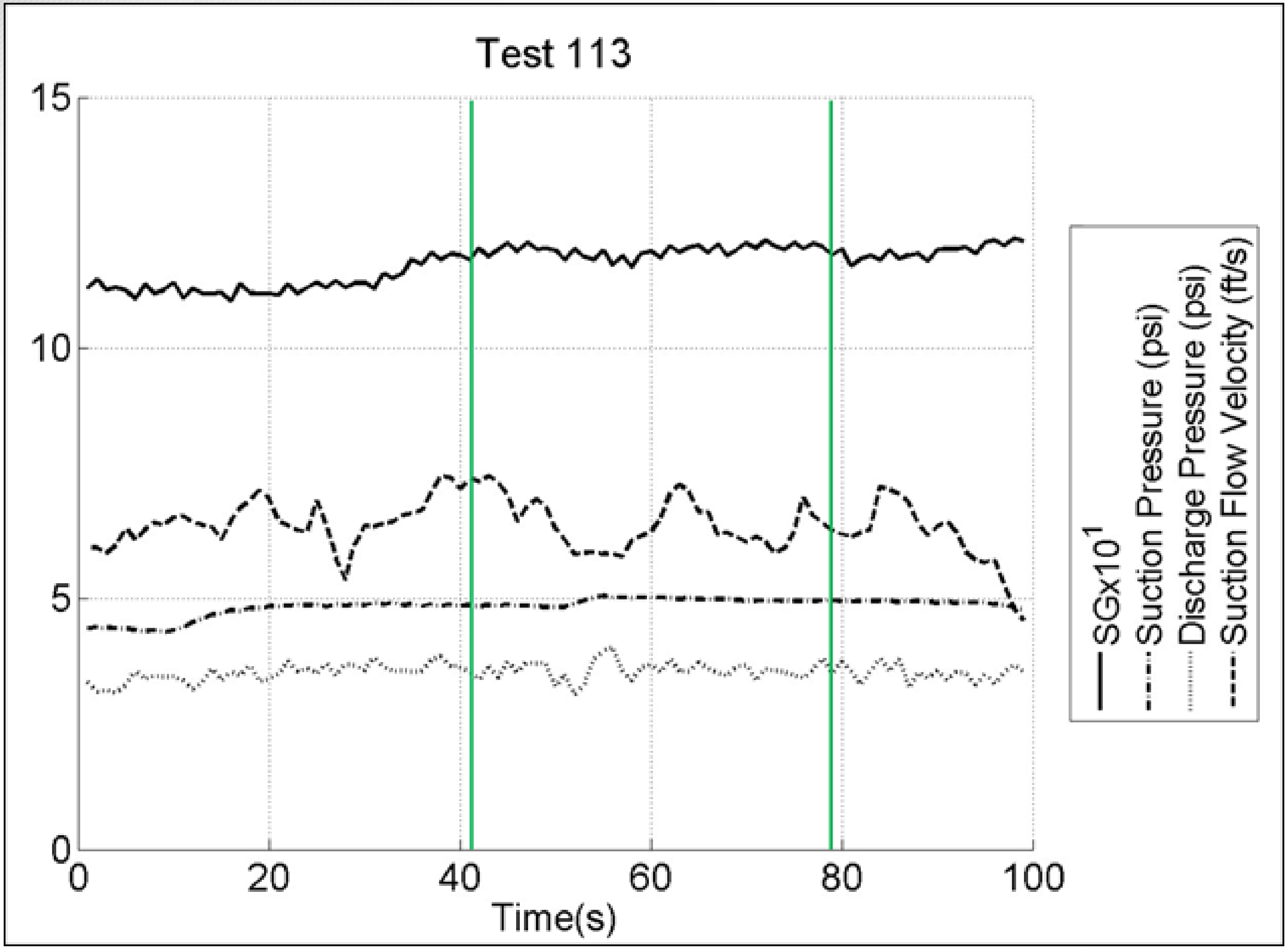
Rosemount, Inc. (2007)

- ToughSonic® distance sensor TS30S1-1V

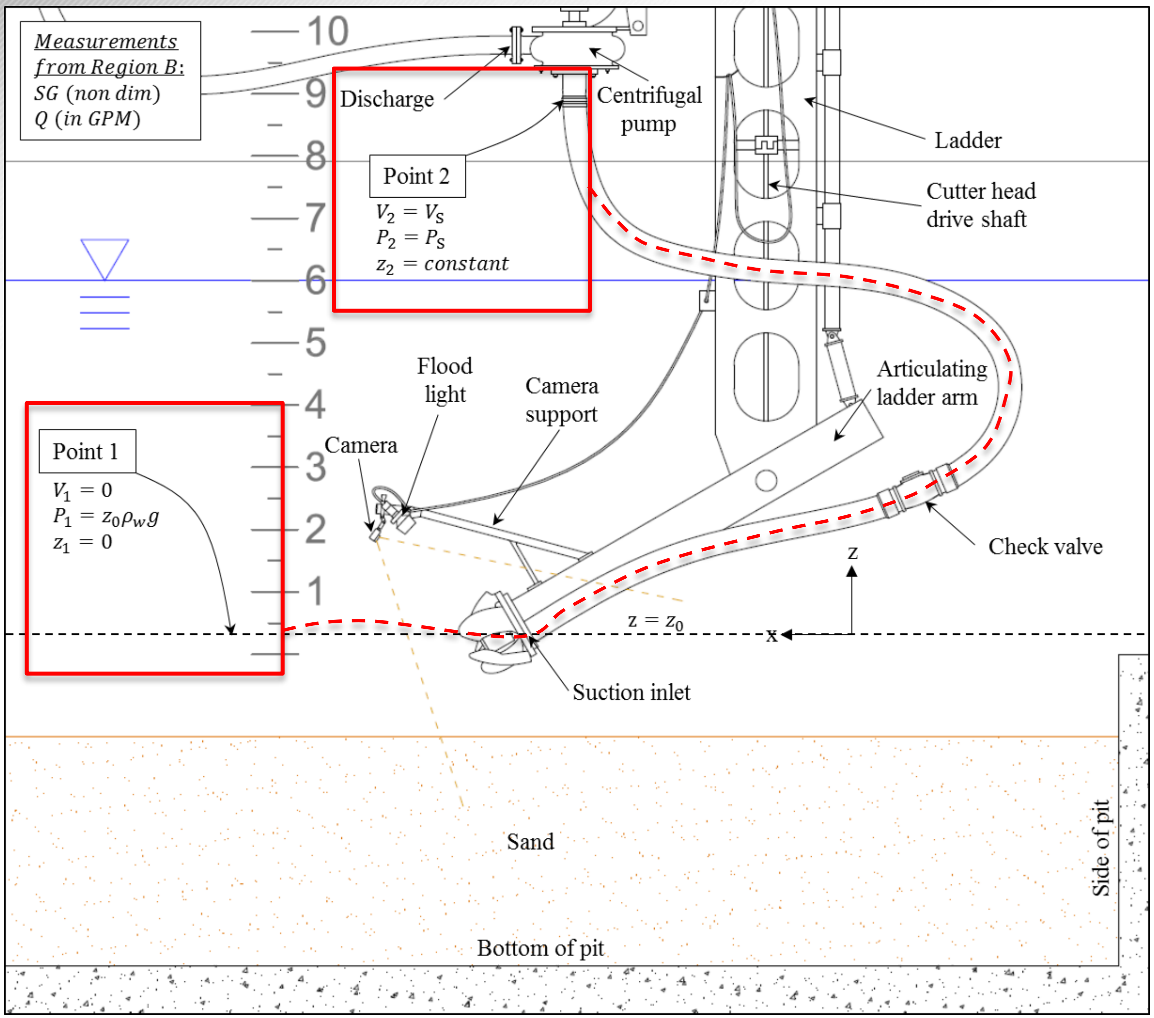
Senix Corporation (2007)


ΔX
ΔY
3
2
ΔX
1
Ω
ΔY
Q
V_L
x
y

DATA PROCESSING



CALCULATION OF K



Conservation of Energy

$$\frac{P_1}{\gamma} + \frac{{V_1}^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \frac{{V_2}^2}{2g} + z_2 + h_L$$

Evaluate at two conditions:

Screen ON

$$\frac{P_{1n}}{\gamma} = \frac{P_{Sn}}{\gamma} + \frac{{V_{2n}}^2}{2g} + z_2 + h_{Ln}$$

Screen OFF

$$\frac{P_{10}}{\gamma} = \frac{P_{S0}}{\gamma} + \frac{{V_{20}}^2}{2g} + z_2 + h_{L0}$$

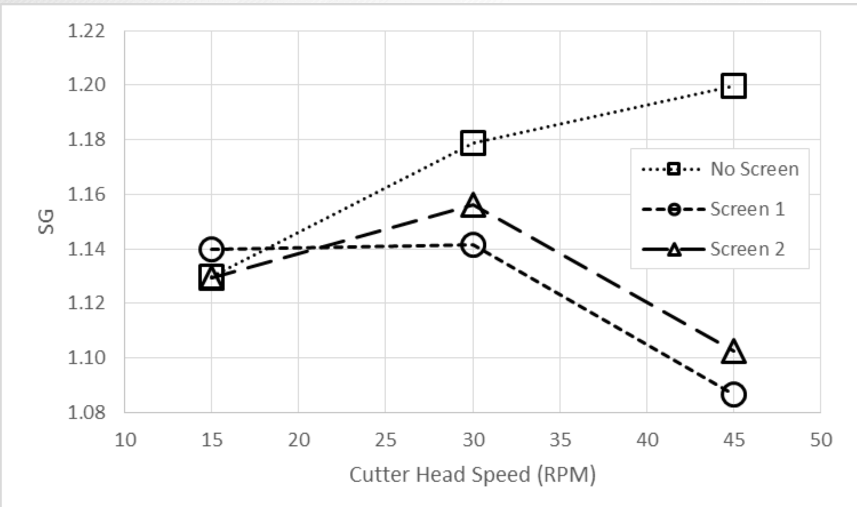
$$\Delta h_{Ln}$$

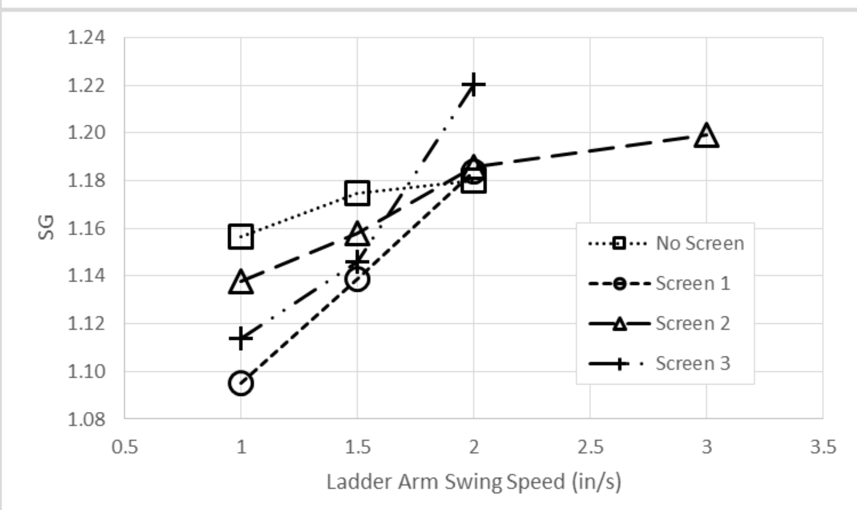
Calculate k

$$k_n = \Delta h_{Ln} \frac{2g}{{V_S}^2}$$

RESULTS

Specific Gravity





Cutter Head Speed Effect

- Optimum **Ω** that maximizes **SG**

Swing Speed Effect

- **SG** ↑ as $\mathbf{V_L}$ ↑

Cutter Head Effects – Spillage

15 rpm

30 rpm

45 rpm

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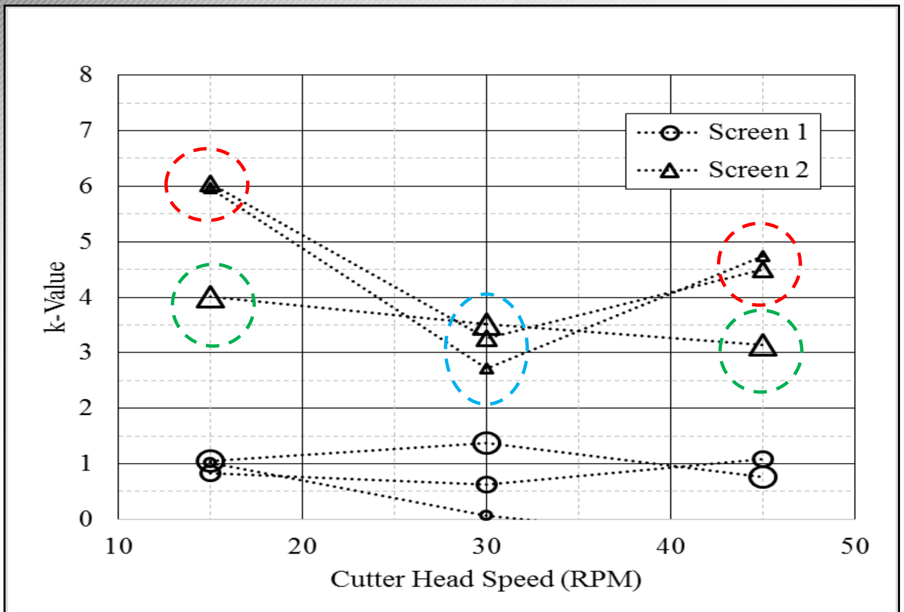
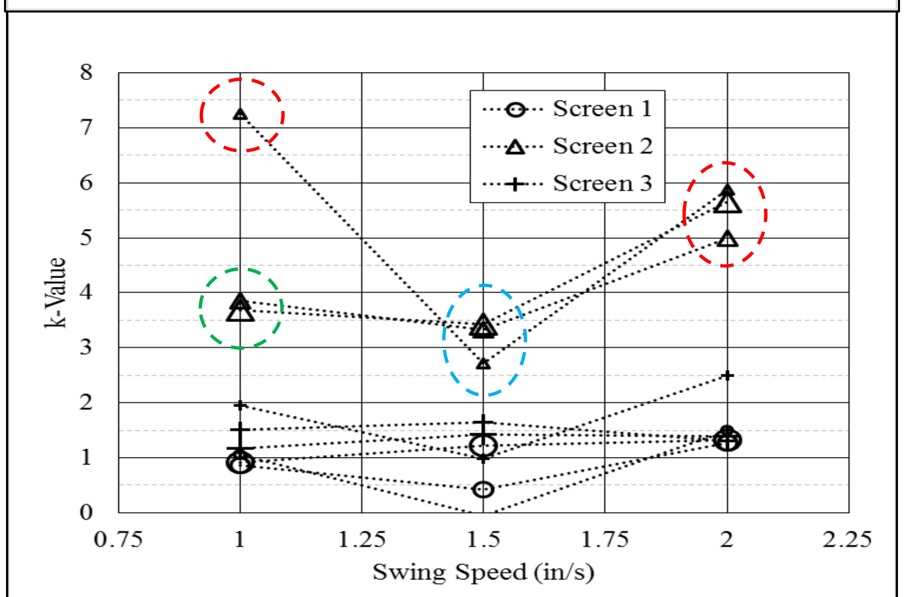
RESULTS



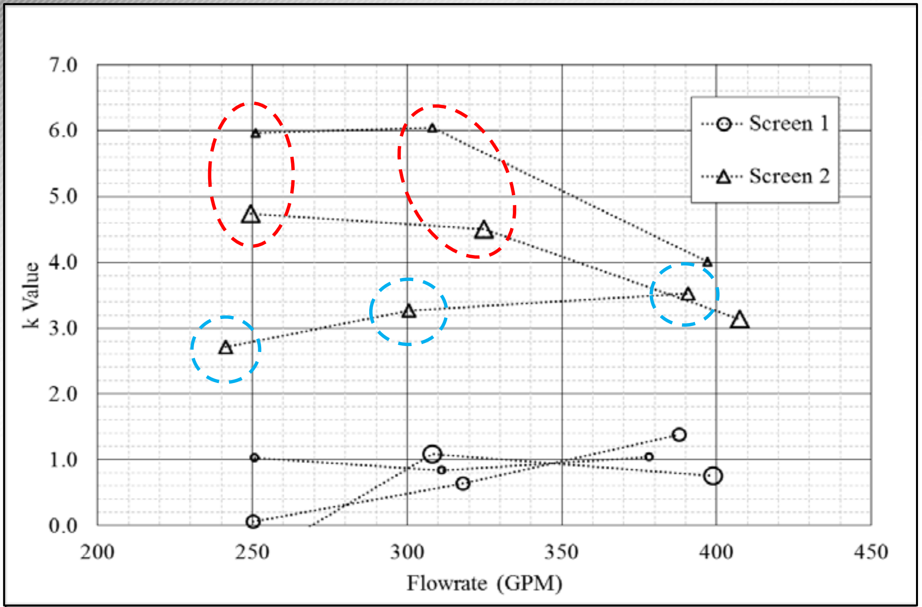


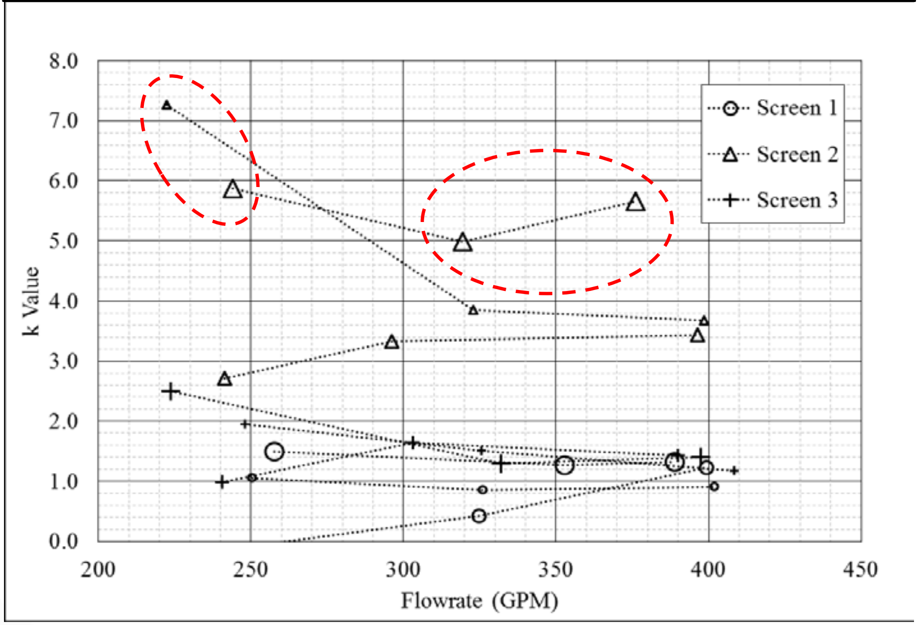
- No consistent **k-value** relationship with **Ω**

Clogged Screen
No clogging
Repeated Tests

- No consistent **k-value** relationship with $\mathbf{V_L}$

RESULTS





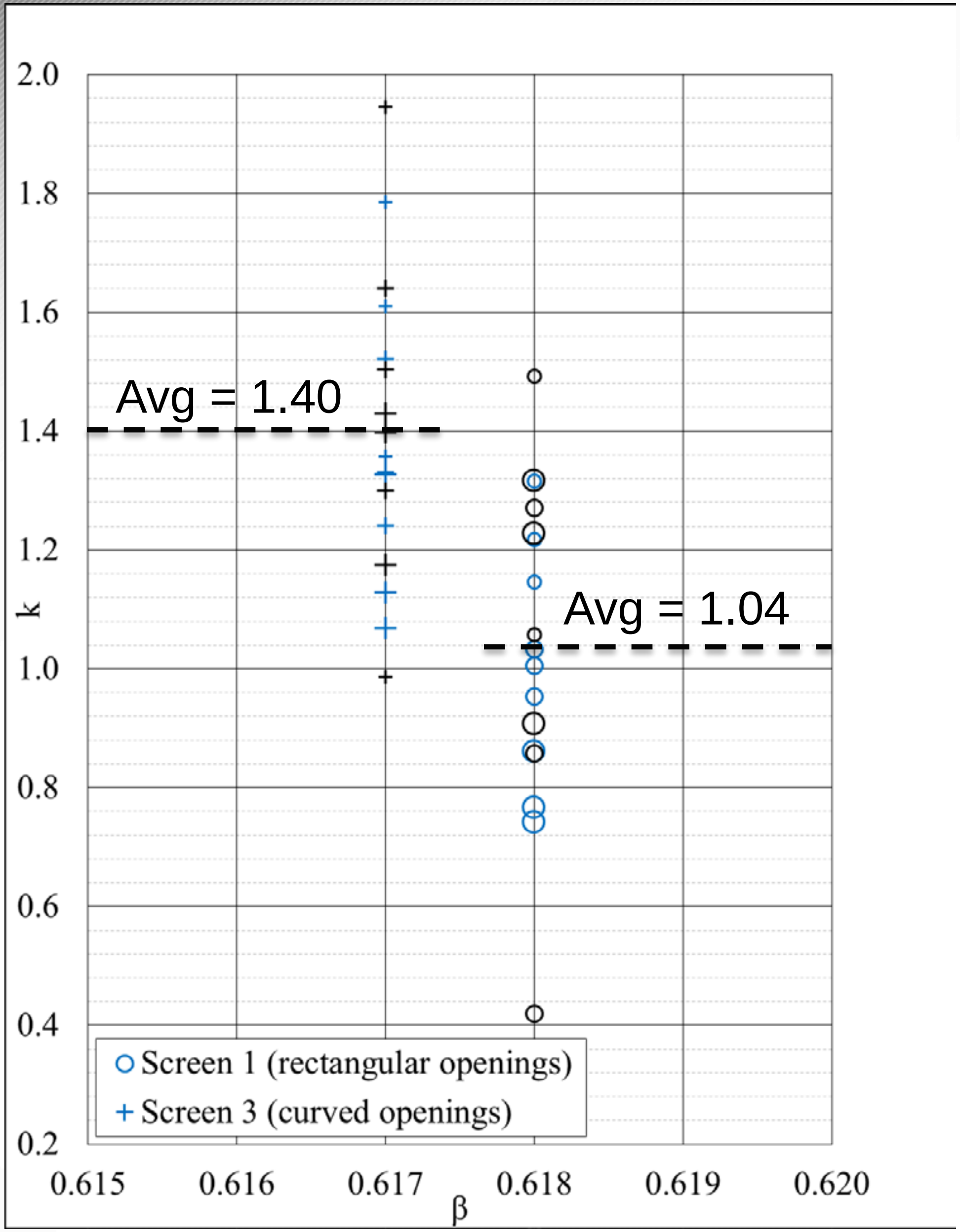
<u>Slurry Tests</u>

- No consistent **k-value** relationship with flow rate (for **Ω** tests)
- k-value **convergence**

Clogged Screen
Repeated Tests

- No consistent **k-value** relationship with flow rate (for $\mathbf{V_L}$ tests)
- k-value **convergence**

RESULTS



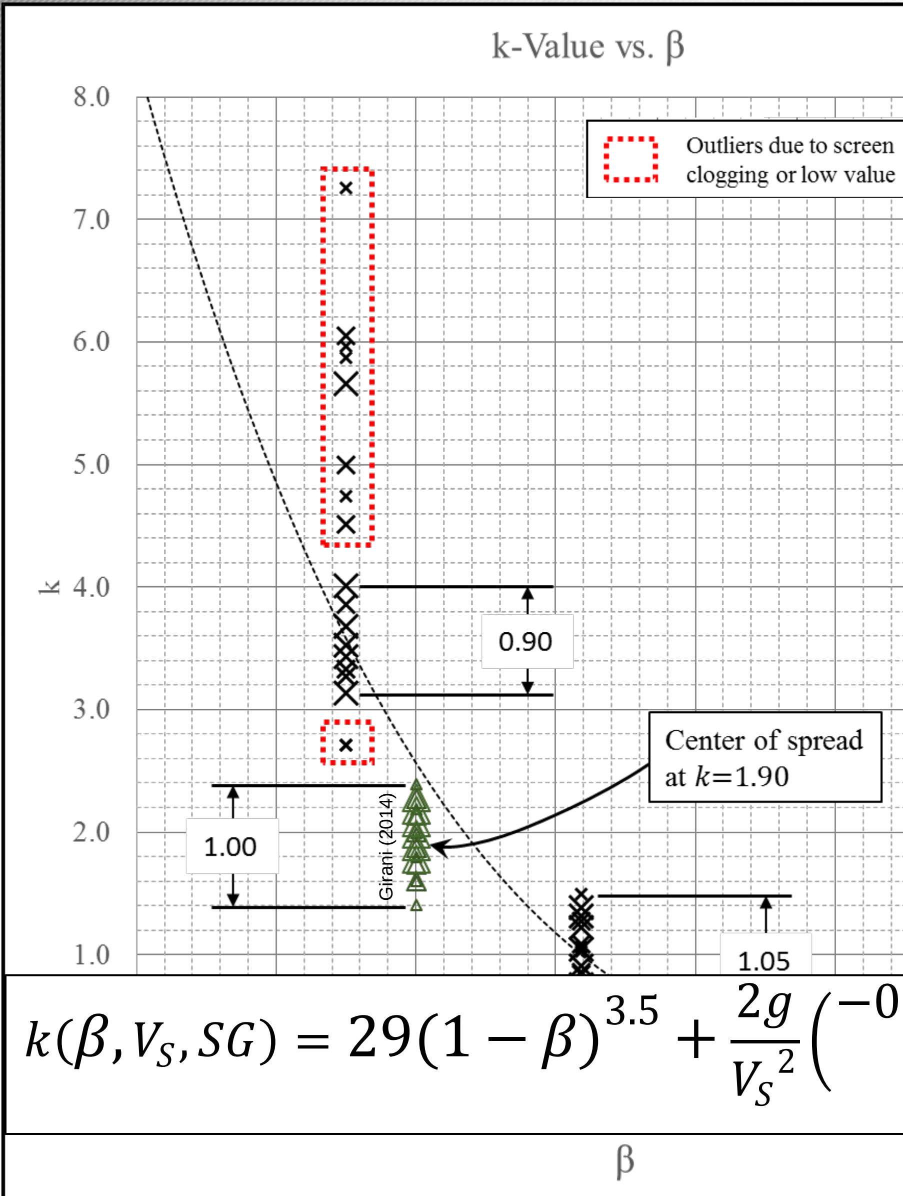
Screen Opening Shape

- Screen 1

- Screen 3

- **Greater average k-value for Screen 3**

RESULTS
k and β – Slurry Tests



Manual Curve Fit

$$k(\beta) = 29(1-\beta)^{3.5}$$

Girani (2014) Equation

$$\frac{2g}{V_S{}^2}\left(\begin{array}{r}-0.694 - 0.442 \cdot V_S + 1.302 \cdot SG \\ +0.0468 \cdot V_S{}^2 + 0.187 \cdot V_S \cdot SG\end{array}\right)$$

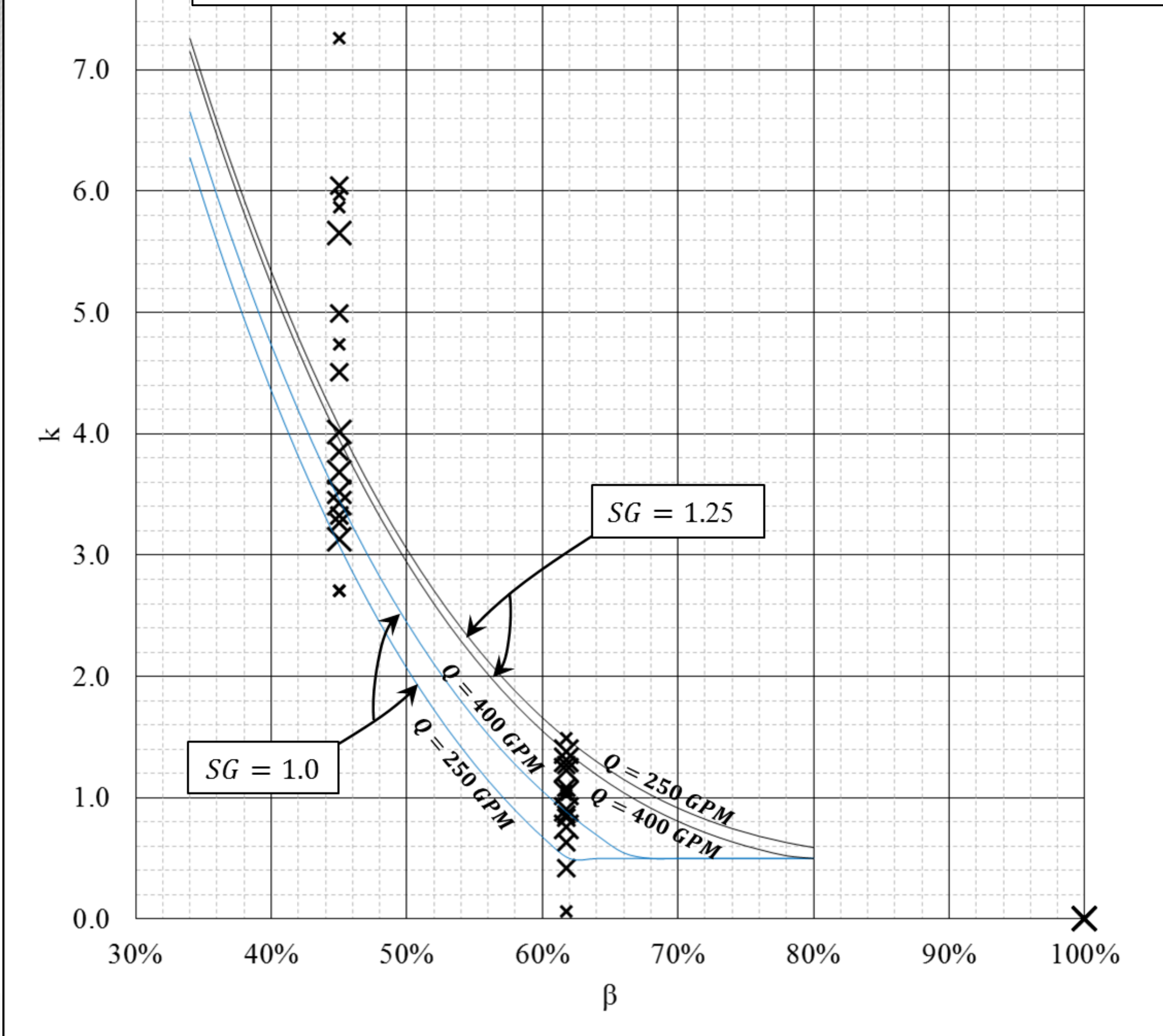
SG and **V$_s$** Correction Term

$$\frac{2g}{V_S{}^2}\left(\begin{array}{r}-0.694 - 0.442 \cdot V_S + 1.302 \cdot SG \\ +0.0468 \cdot V_S{}^2 + 0.187 \cdot V_S \cdot SG\end{array}\right) - 1.90$$

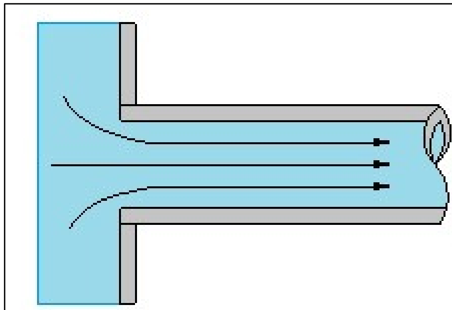
$$k(\beta, V_S, SG) = 29(1-\beta)^{3.5} + \frac{2g}{V_S{}^2}\left(\begin{array}{r}-0.694 - 0.442 \cdot V_S + 1.302 \cdot SG \\ +0.0468 \cdot V_S{}^2 + 0.187 \cdot V_S \cdot SG\end{array}\right) - 1.90$$

RESULTS
k and β – Slurry Tests

$$k(\beta, V_S, SG) = 29(1-\beta)^{3.5} + \frac{2g}{V_S{}^2}\left(\begin{array}{r}-0.694 - 0.442 \cdot V_S + 1.302 \cdot SG \\ +0.0468 \cdot V_S{}^2 + 0.187 \cdot V_S \cdot SG\end{array}\right) - 1.90$$



- Plotted over experimental data



(Amirault, 2014)

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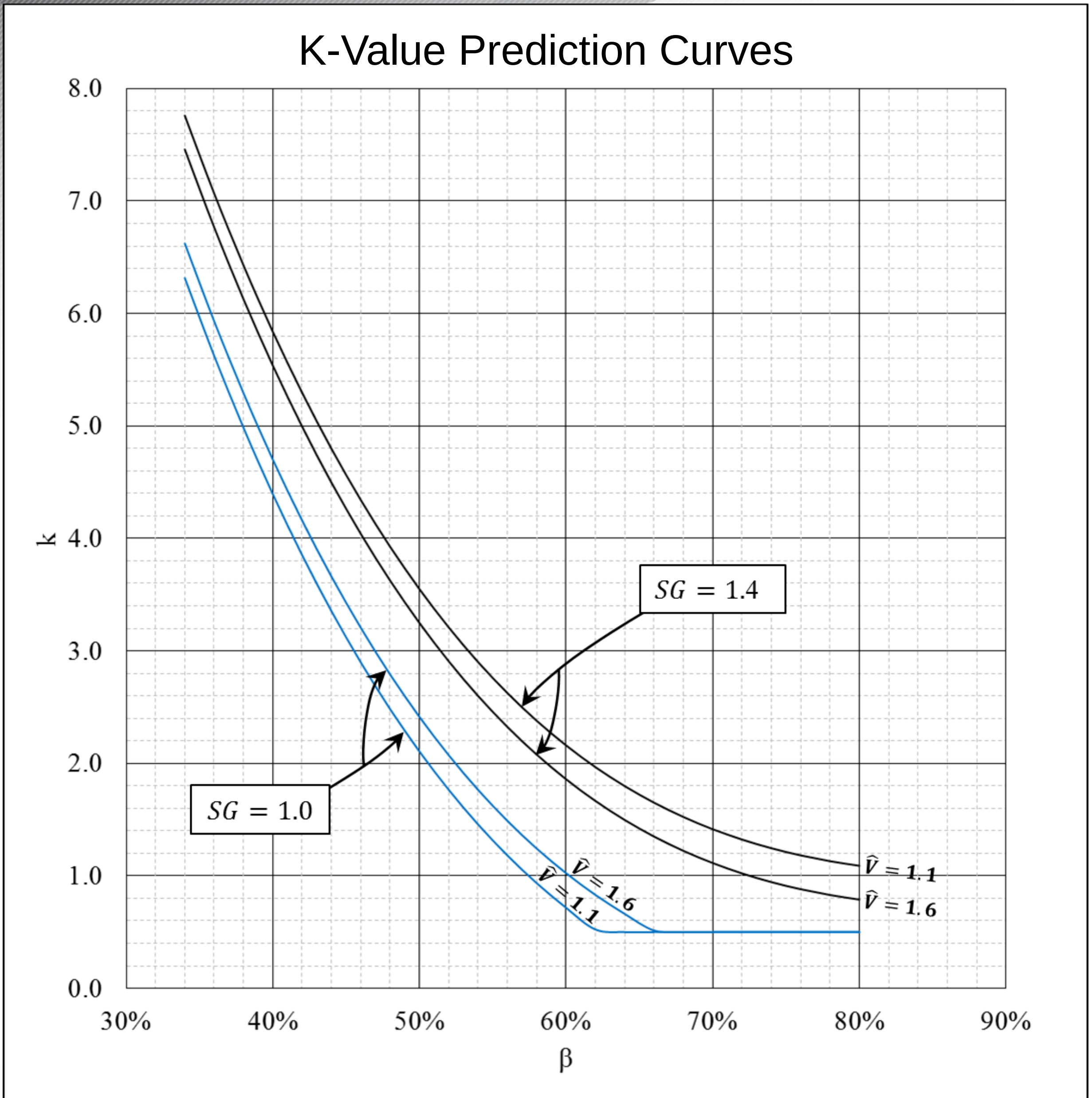
RESULTS
k and β – Slurry Tests



- Non-dimensional plot
- Extrapolated to common dredging parameters
- $1.1 \leq \hat{V} \leq 1.6$
- 1.0 ≤ **SG** ≤ 1.4
- Minimum k-value of 0.5

CONCLUSIONS

<u>Conclusion</u>

- No direct correlation between screen **k-value** and **Ω** or $\mathbf{V_L}$
- k-value increases exponentially with decreasing **β**
- Screen opening shape may change the screen's inherent **k-value**
- k-values converge at high $\mathbf{V_S}$ and **SG**
- Screen clogging at Haynes Lab may occur at **β** < 0.50

Girani (2014)

CONCLUSIONS

Conclusion

- Spillage increases with **Ω**

Hayes, et al. (2000); Henriksen, et al. (2011)

- **SG** and production increase with $\mathbf{V_L}$

Yagi, et al. (1975)

- Optimum **Ω** exists (**Ω** is limited by $\mathbf{V_L}$**)**

den Burger, et al. (1999)

- k-value prediction equation may be used for model or full-size dredges

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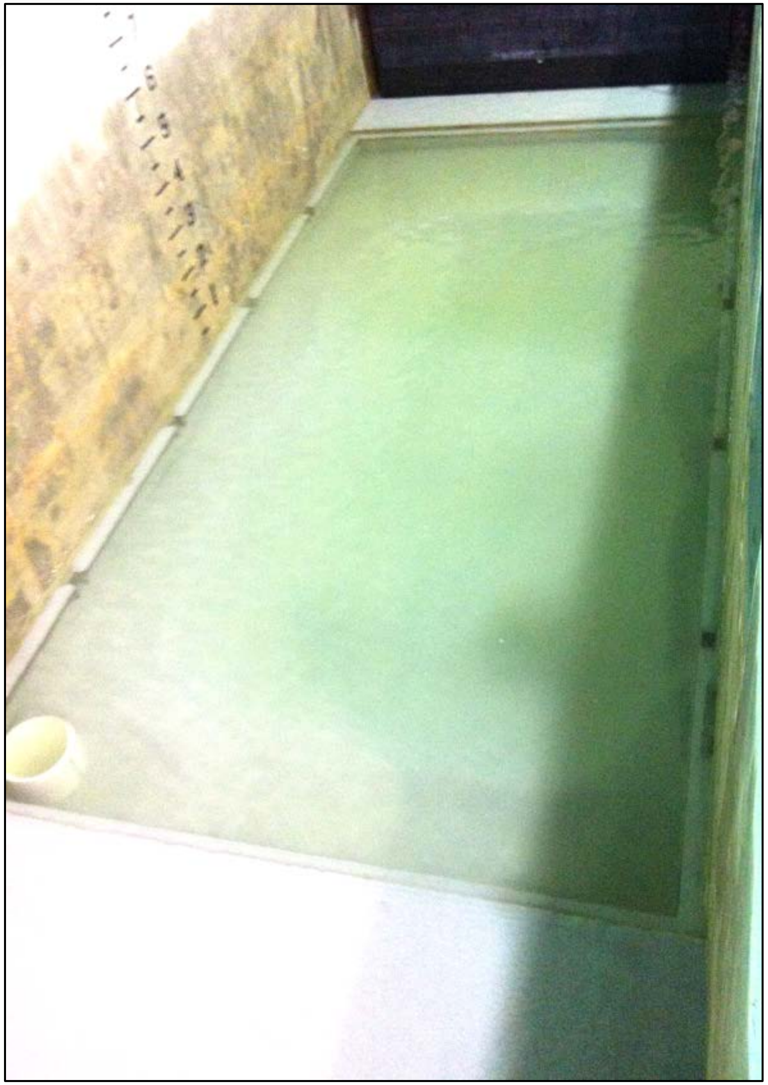
RECOMMENDATIONS

- Future Experiments
  - Larger range of **Ω**
  - Larger range of $\mathbf{V_L}$
  - More **β**-values
  - Different screen opening shapes

  - Take measures during testing to prevent screen clogging when **β** < 0.50
  - Investigate methods to prevent screen clogging
  - Automated flow control of dredge pump

PHOTOS



PHOTOS

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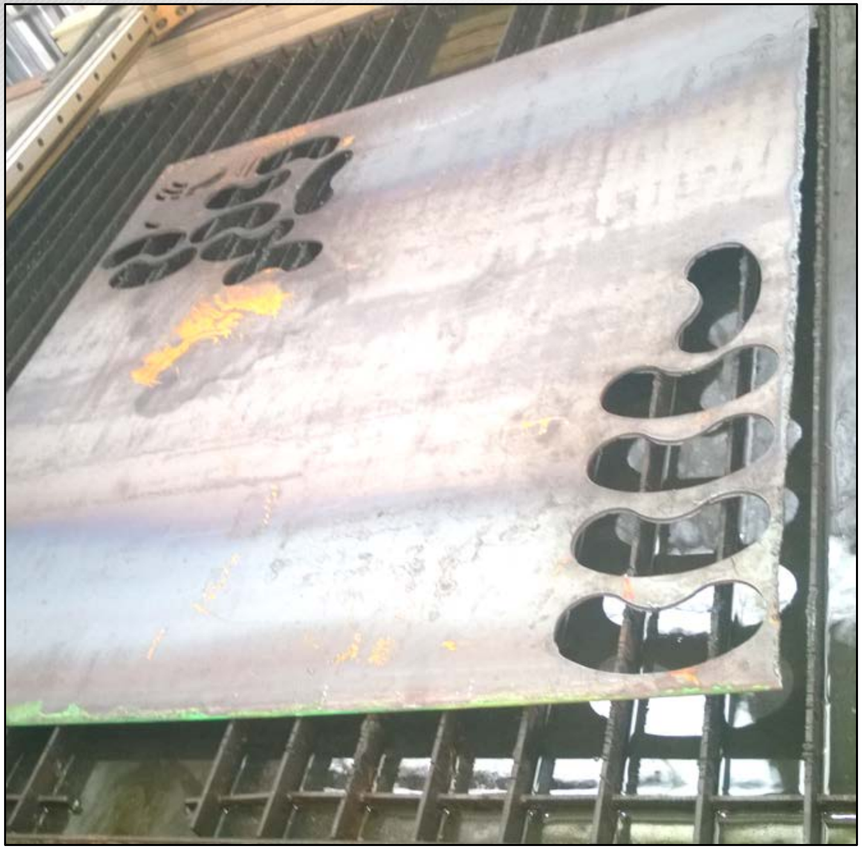

QUESTIONS?

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