Oak Ridge National Laboratory

Characterization of modern dip-tubes with classical nondimensional numbers

ACEEE
Hot Water Forum

Session 7 B

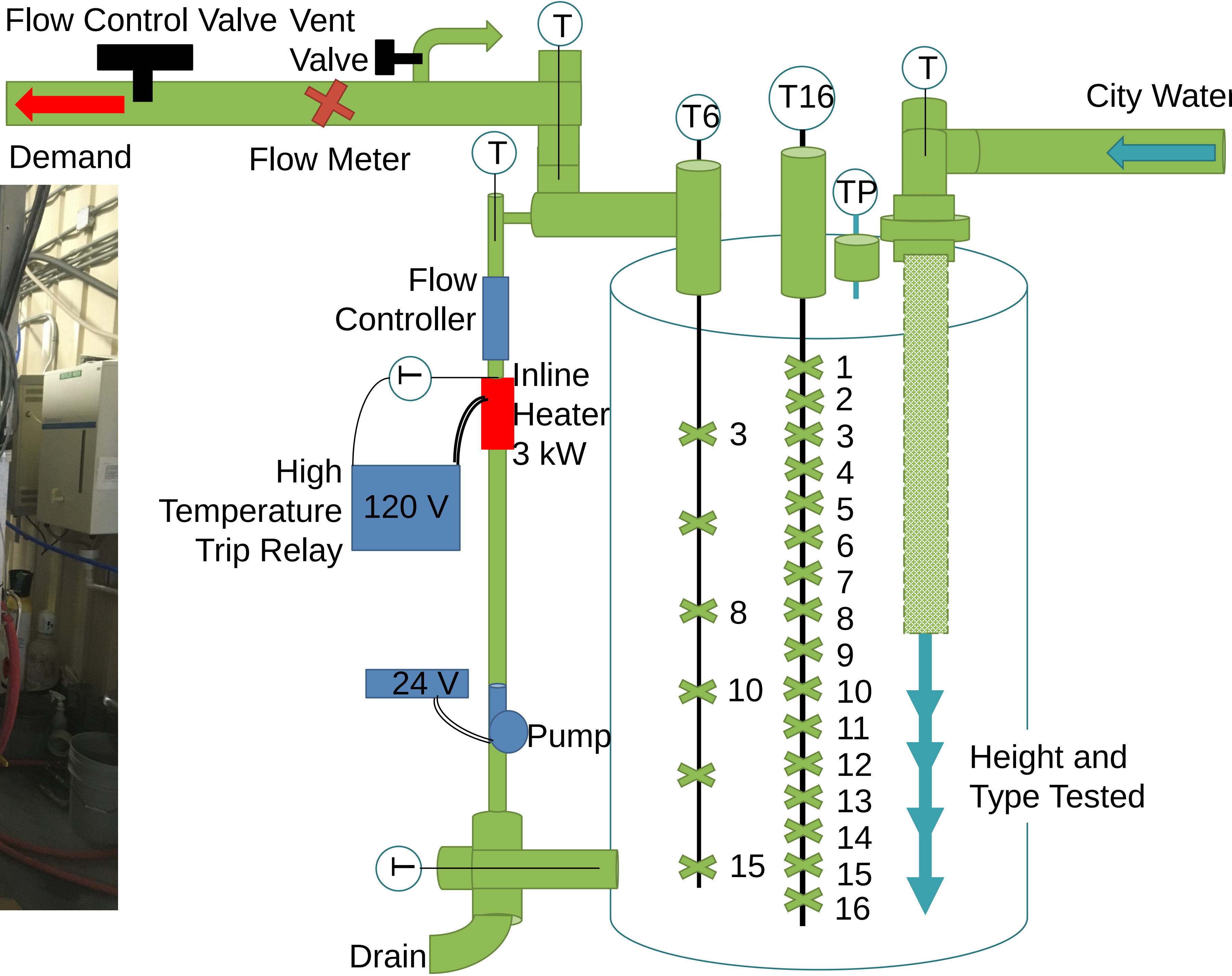
3/13/2018

Joe Rendall

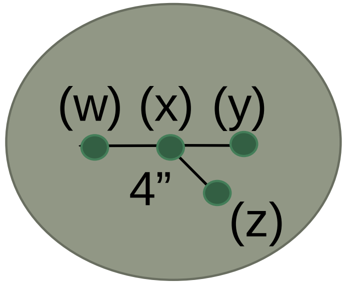
Outline

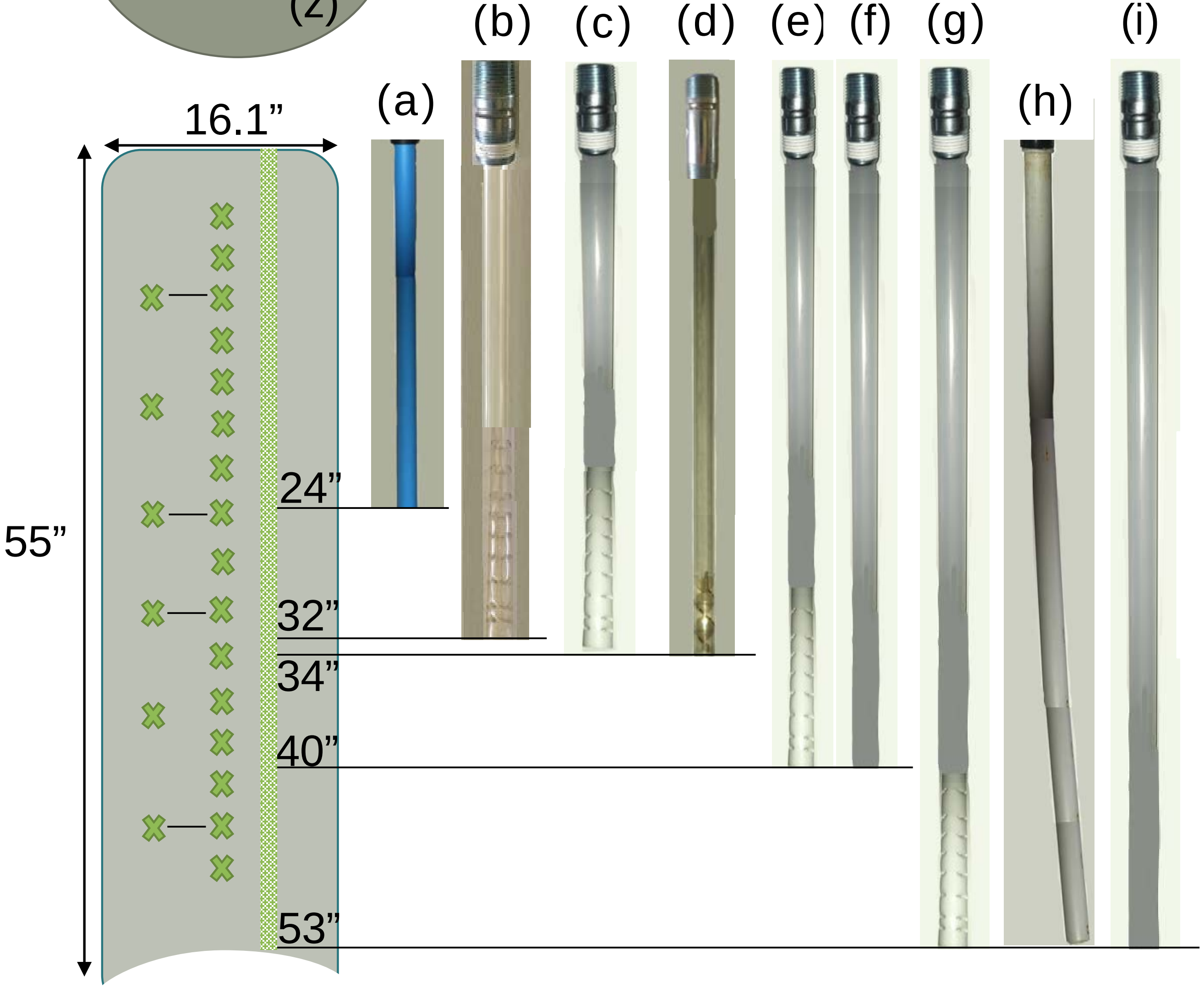
- Experimental setup
    - tank geometry, TC locations
    - P&ID and Instrumentation specifications
    - Initial conditions
    - Draw profiles (gal, GPM)
- Experimental results
    - Show experimental data graphs and animations
    - Comparisons between dip-tube types in data
- Model approaches (1D-2D-3D)
    - Introduce eddy diffusivity
    - Table of eddy diffusivity observed for dip-tube type 1
- Conclusions

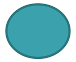
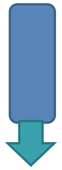
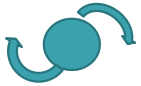
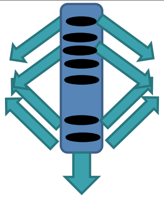
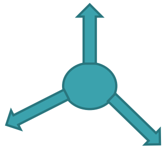
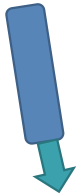
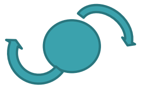
Experimental Setup



Hypothesis: A flow property developed by each diffuser type (characterized by Richardson and Reynolds number), is distinct and interaction will walls (installation height) will also affect this flow property.





Type of diffuser	Exit Flow (Profile)	Exit Flow (Plan)
Nonperforated (a), (f) and (i)		
Heliacal (d)		
Slit perforations (b), (c), (e), (g)		
Heliacal and curved (h)		

Instrumentation specifications and uncertainty

Equipment	Specification
RHEEM® 50 gallon residential tank	UEF 0.93 FHR 63 gallons* Volume 45.2 gallons
National Instruments logging chassis	cDAQ-9178
Inline resistance heater	3 kW
24 Volt variable power supply	0.01 volt resolution
Iwaki pump	1/20th hp direct drive
VCTL	27 kW

Instruments	Specification	Uncertainty
NI-9214 module Type T, 1/16” diameter, ungrounded thermocouples	+- 78 mV, 68 S/s 0.55 s thermal constant 0.5 °C for probe	1.2 degF
AliCat® Liquid Flow Controller	0 to 1.7 GPM	+- 0.007 GPM @ 0.18 GPM
Flow meter	0 to 3.5 GPM	+- 2%
Bucket & stop watch	1 liter gradation	+- 2%**
Rotameter	0 to 3 GPM	+- 10%**

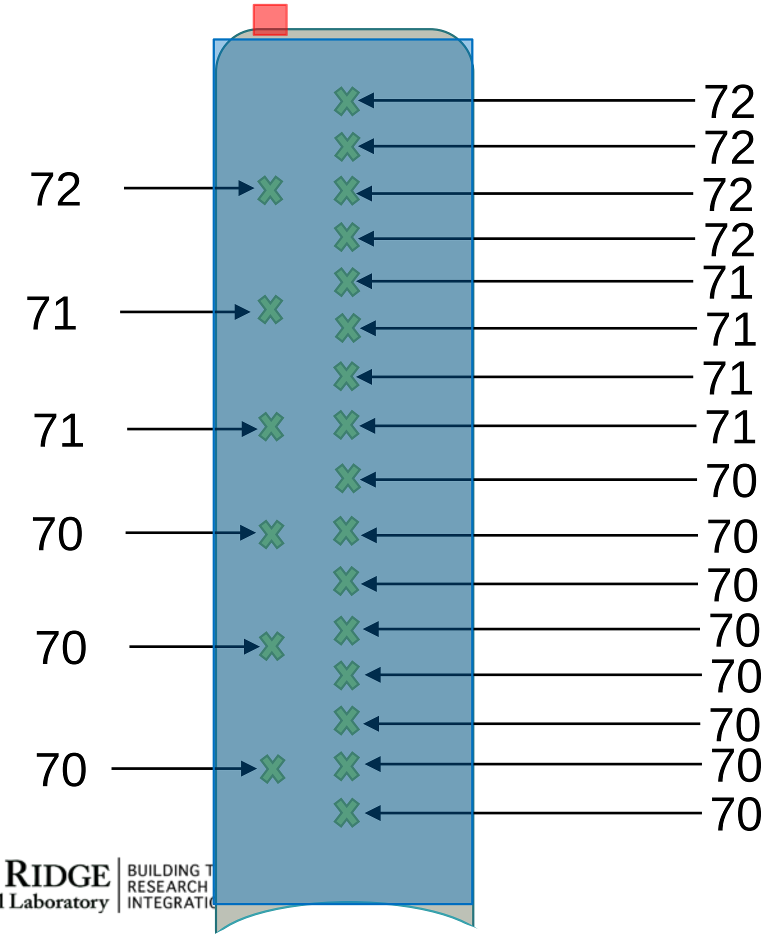
Propagated Error	3% by RSS method

* Not using electric heater for recovery

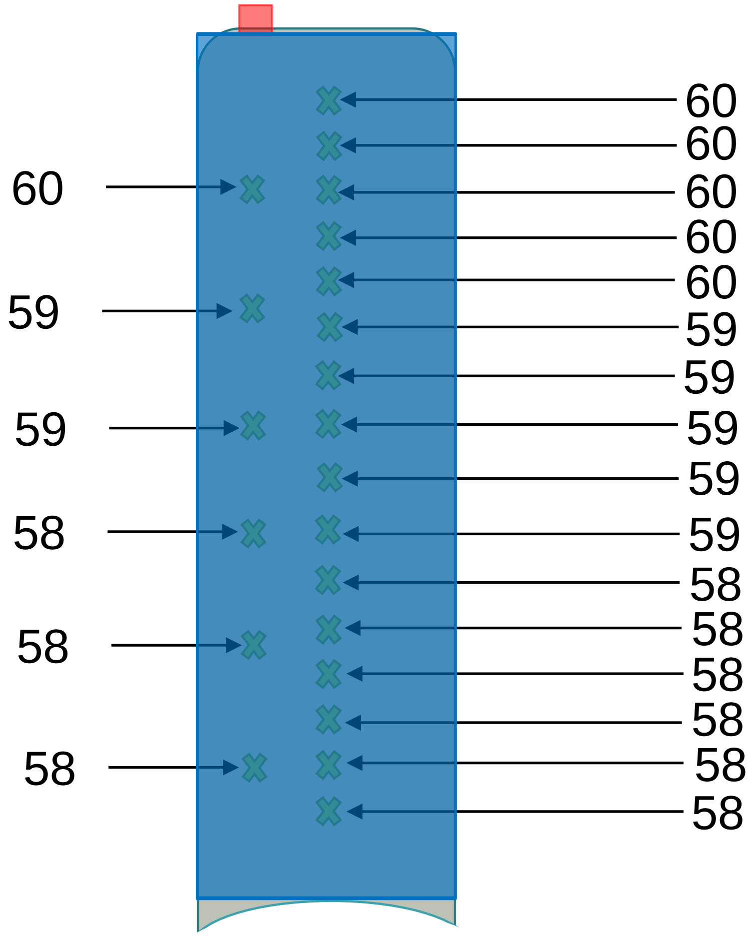
**Only used to estimate set point or verify flow

Heating initial conditions

Typical Initial Condition Summer



Typical Initial Condition Winter



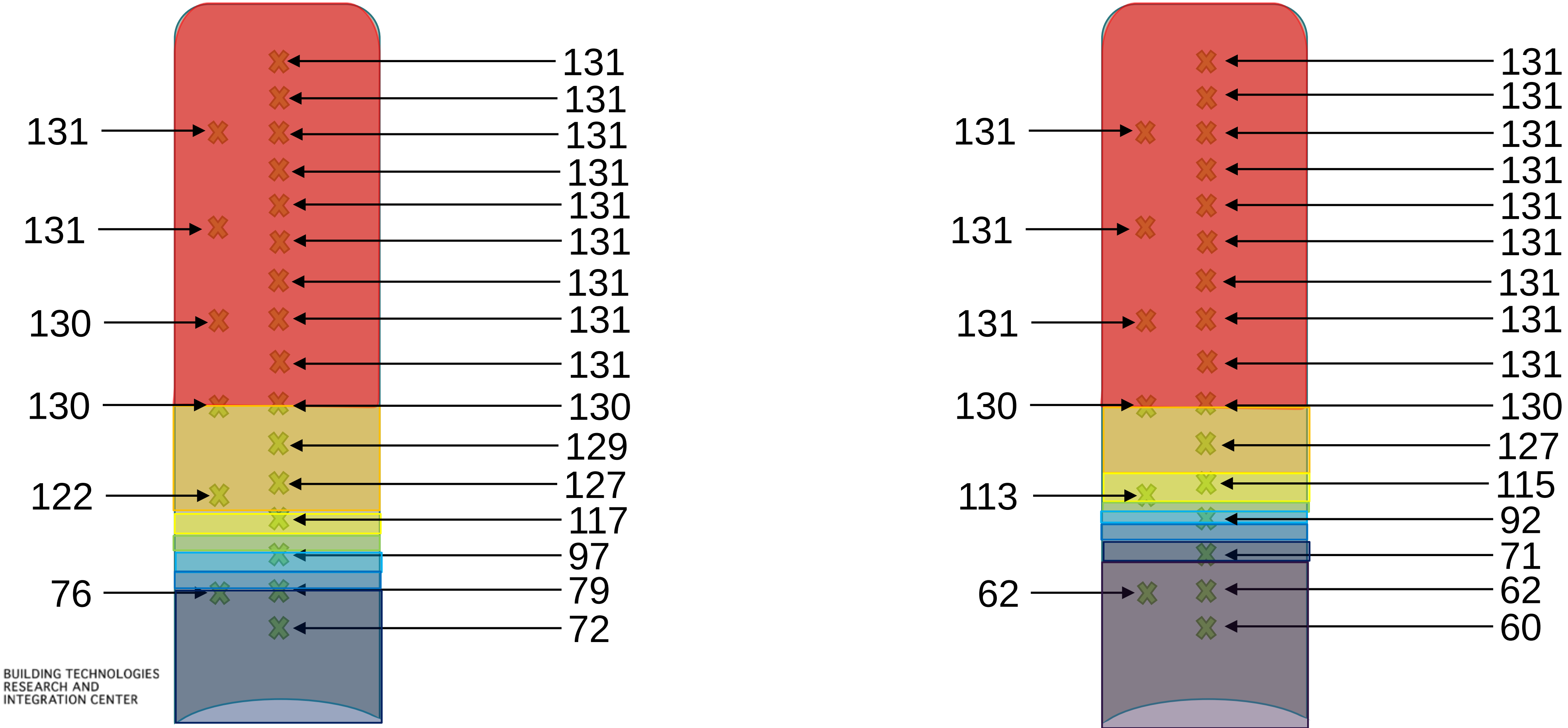
Draw initial conditions, constant temperature

Typical Initial Condition Summer

0.2 GPM

Typical Initial Condition Winter

0.18 GPM



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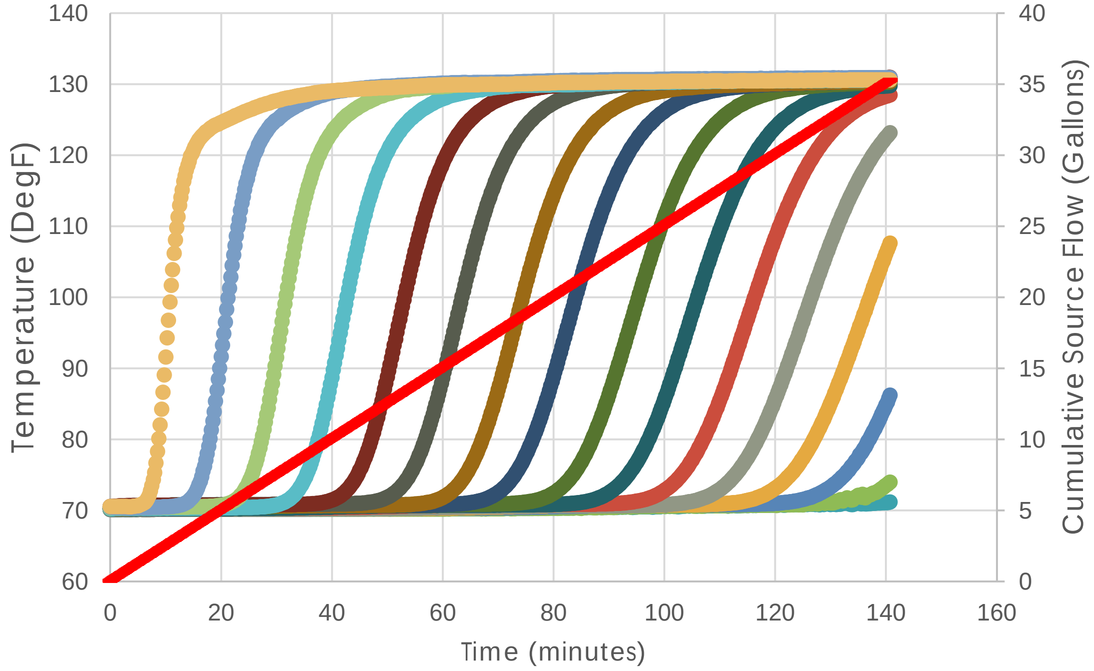
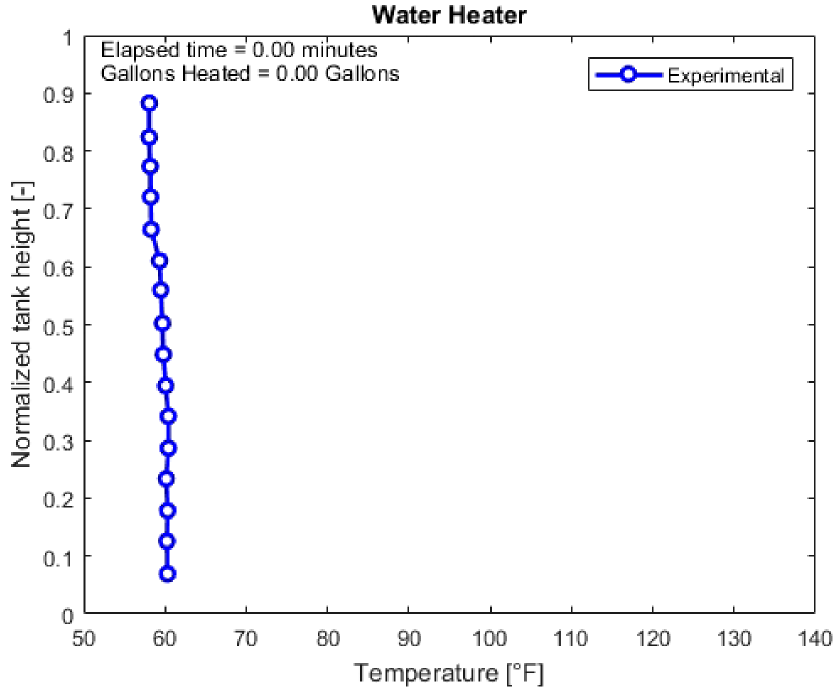
Heating data

Typical Graph



Typical Video



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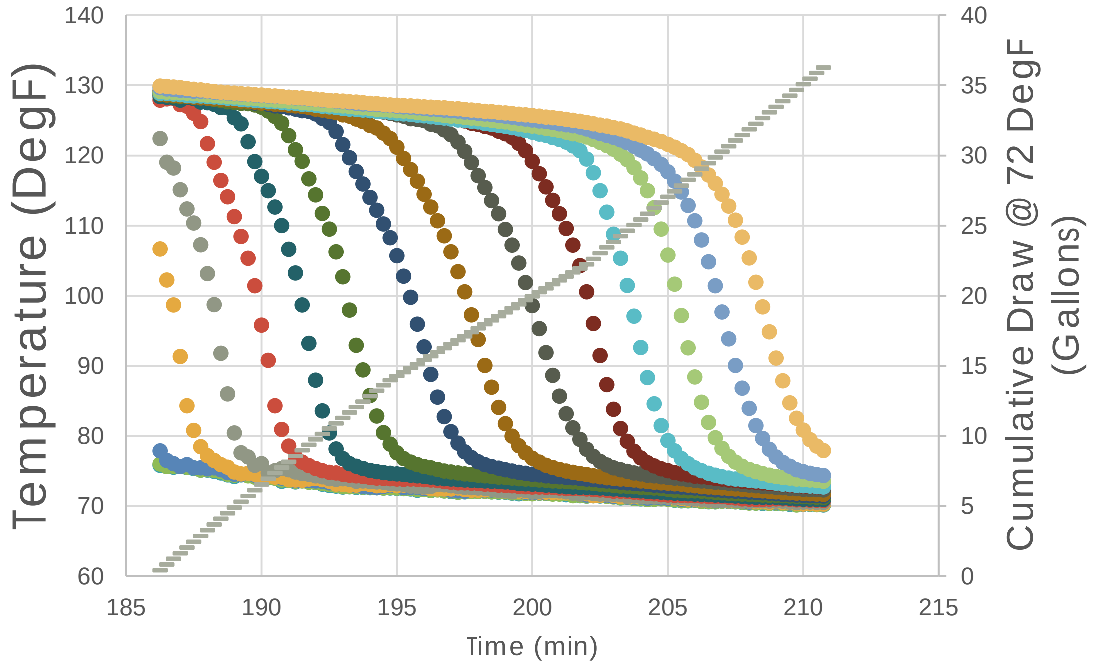
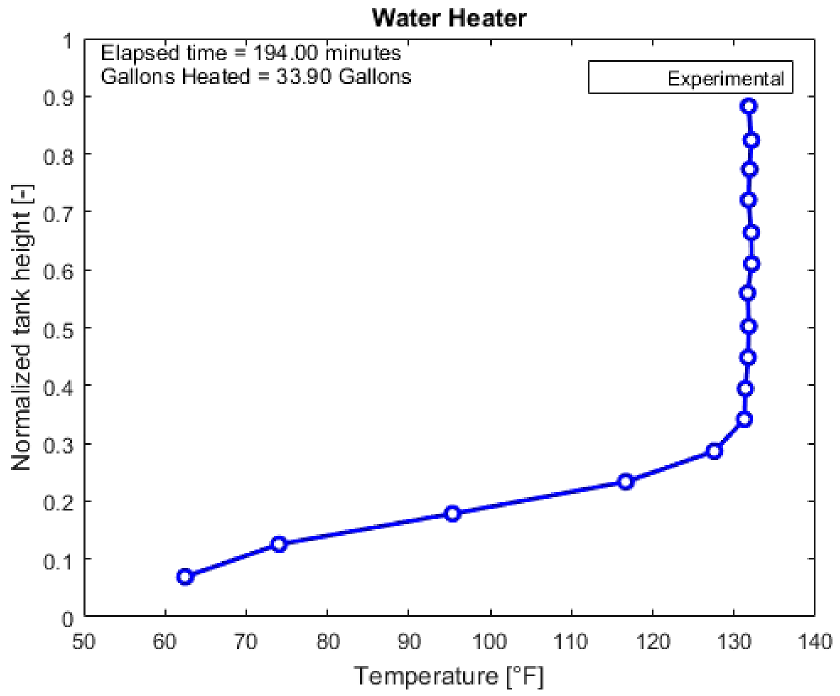
Draw Rates

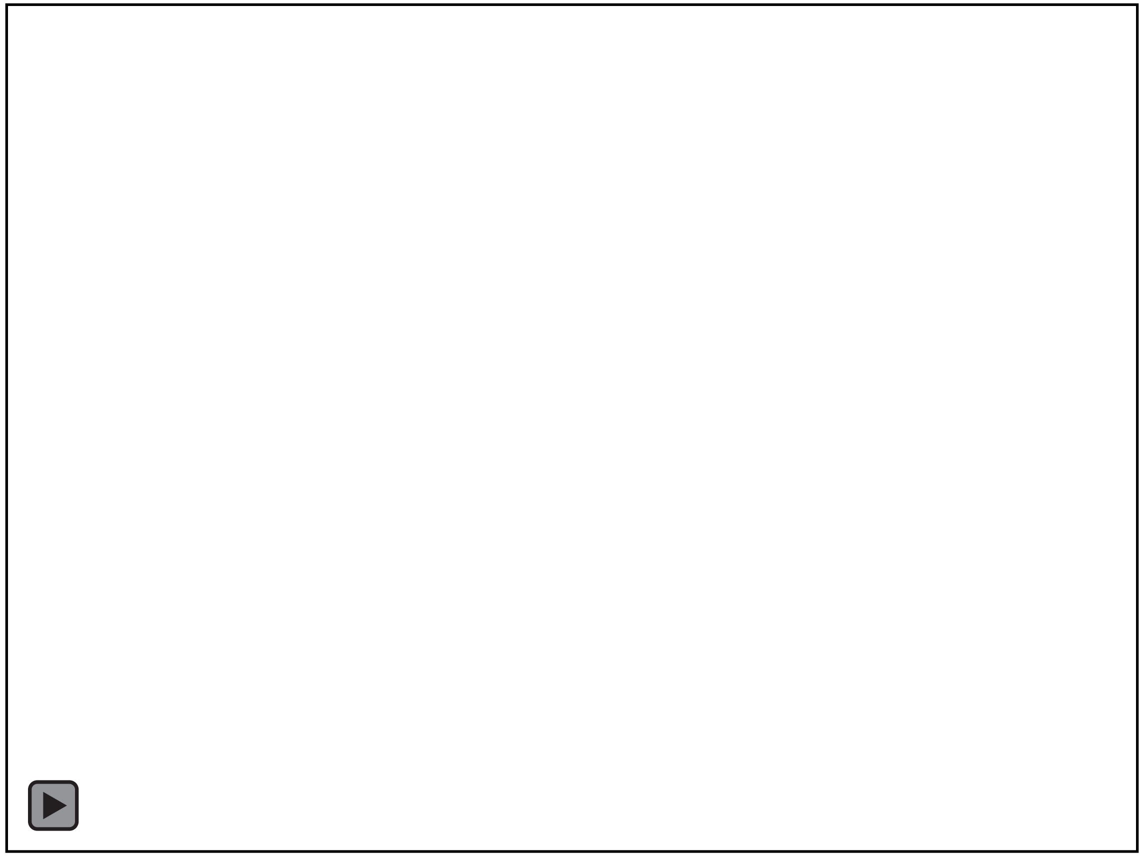
1.5 to 1.9 GPM Continuous Draw



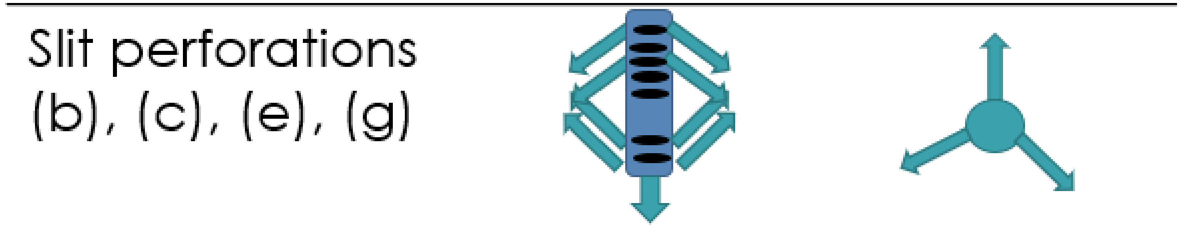
1.7 GPM Continuous Draw



Dip-tube draw comparisons (1.6 +- .2 gpm for 50 gallons)



Modeling

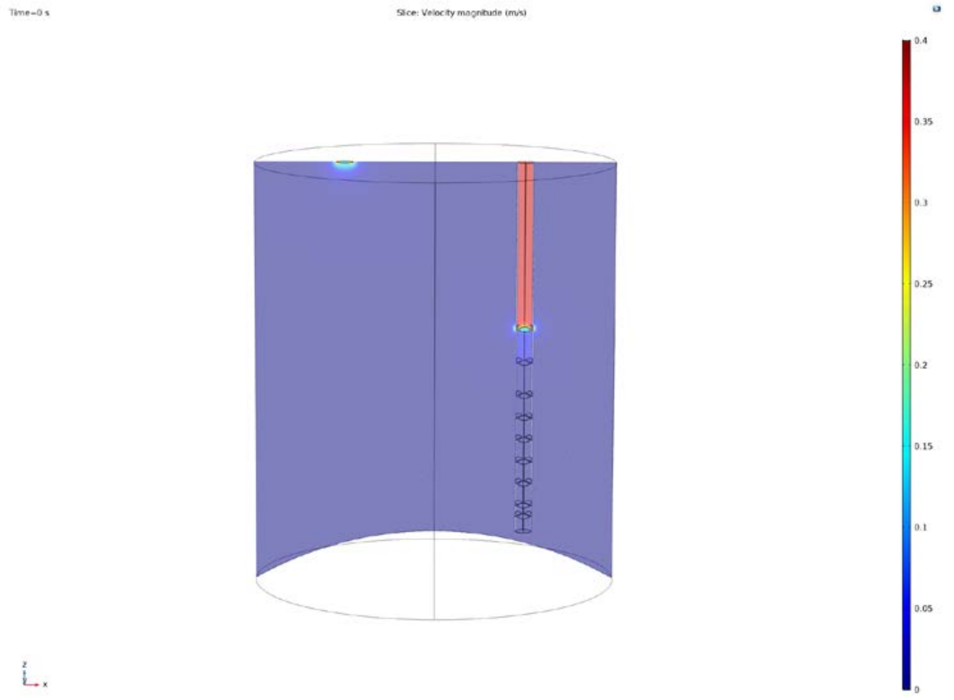


Models (1D)

- Mixed tank
- Plug flow
- Combination of plug flow and mixing
- Convection (plug flow) and diffusion
- Convection (plug flow), diffusion and eddy diffusion

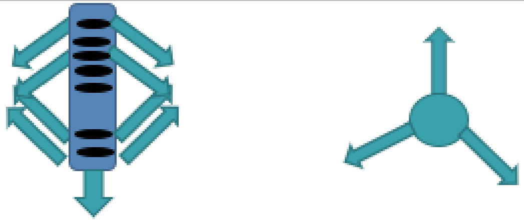
Computation Time

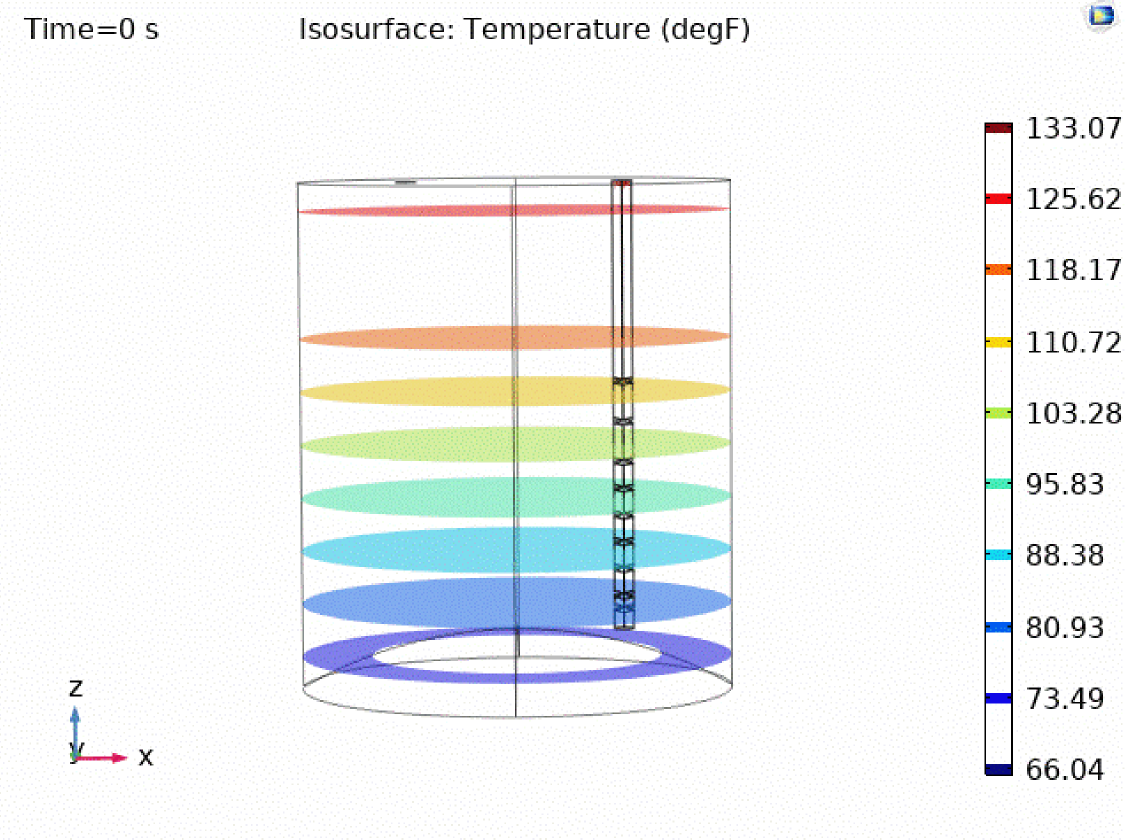
3D simulation



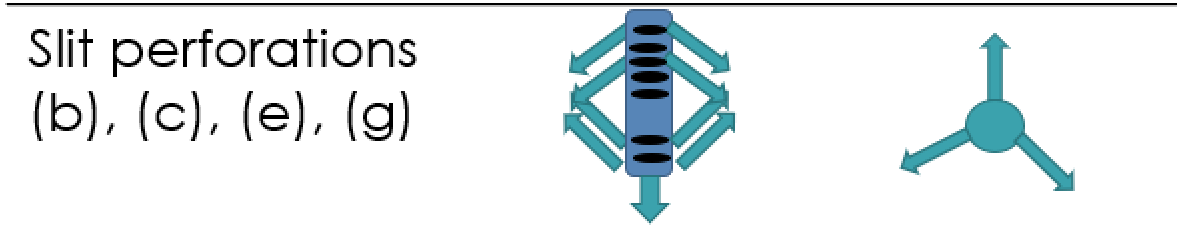
Simulations

Slit perforations
(b), (c), (e), (g)





Simulations



Modeling

Models (1D)

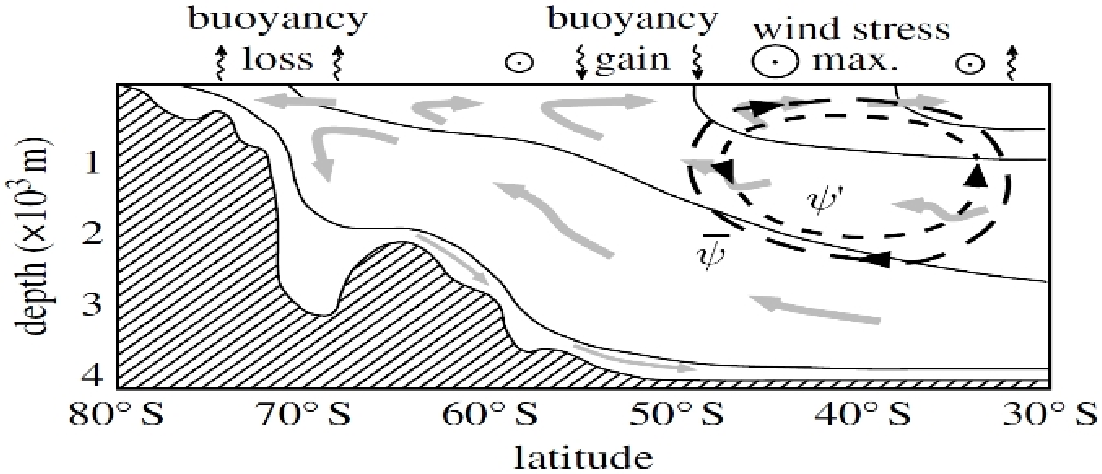
- Convection (plug flow), diffusion with eddy diffusion

$$v\frac{\partial T}{\partial y} = (\alpha + \varepsilon)\frac{\partial^2 T}{\partial y^2}$$

$$a\left(\frac{Re}{Ri}\right)^b = (\alpha + \varepsilon)/\alpha$$

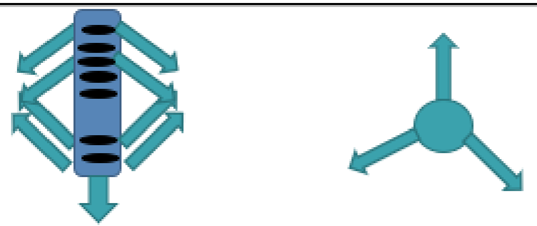
Correlation to Re/Ri
(Oppel & Zurigrat late 1980's)

Eddy Diffusivity

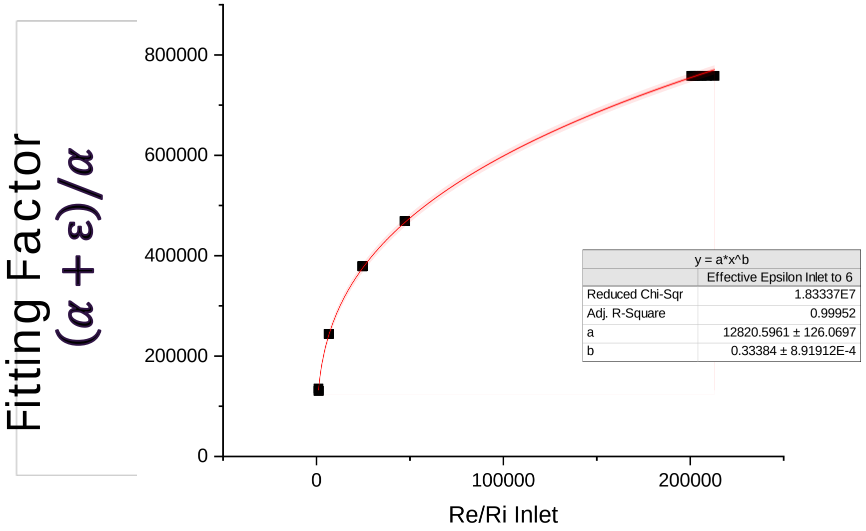


Initial Results

Slit perforations
(b), (c), (e), (g)



Typical Inlet Fitting Factor



Fitting Results

Dip-tube Installation Height	a	uncertainty in a	b	uncertainty in b	Maximum Factor
32"	38,300	600	0.326	.0012	2,500,000
40"	12,800	130	0.33384	0.00009	800,000
40"*	10,960	70	0.3367	0.0006	800,000
53"	3250	70	0.329	0.002	100,000
*lower Ri initial condition					

$$a\left(\frac{Re}{Ri}\right)^{b} = (\alpha + \varepsilon)/\alpha$$

Conclusions

- Experiments < 3% errors
- 16 TC grid improves resolution
- Simple plug flow models total energy well outside of thermocline
- Empirical methods to modify simple plug 1D plug flow
- A first principal model may be viable by sampling at maximum local Richardson number

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Your Questions Please