Quantifying Multiphase Flow Behavior in Small-Diameter Vertical Pipes

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Introduction

Umaer Abdullah Zaki

- 1^{st} year Masters Candidate
- From Dhaka, Bangladesh
- Working with Dr. Burt Todd, quantifying multiphase flow in small-diameter pipes

Presentation

- Review Matt Malin's work
- Montana Tech Vertical Flow Loop (MTVFL) Enhancements
- Future Research Goals using the MTVFL
- My Personal Research Focus

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Previous Work

- "An Investigation into the Mechanisms of Liquid Loading in Small-Diameter Vertical Pipes"
  - Masters Thesis, Matt Malin, 2019

- SPE Paper #23OKOG-P-128-SPE, “An Investigation into the Mechanisms of Liquid Loading in Small-Diameter Vertical Pipes”
  - Presented at 2023 SPE OKC Oil & Gas Symposium – Matt Malin
  - Presented at the 2023 Montana Tech SPE Symposium – Burt Todd

Motivation for Malin’s Work

- Liquid loading of gas producers limits their late-life productivity
- Sometimes excess liquid can be removed from gas wells using small-diameter “siphon strings” to produce the liquids
- Multiphase flow in small diameter pipes is poorly understood

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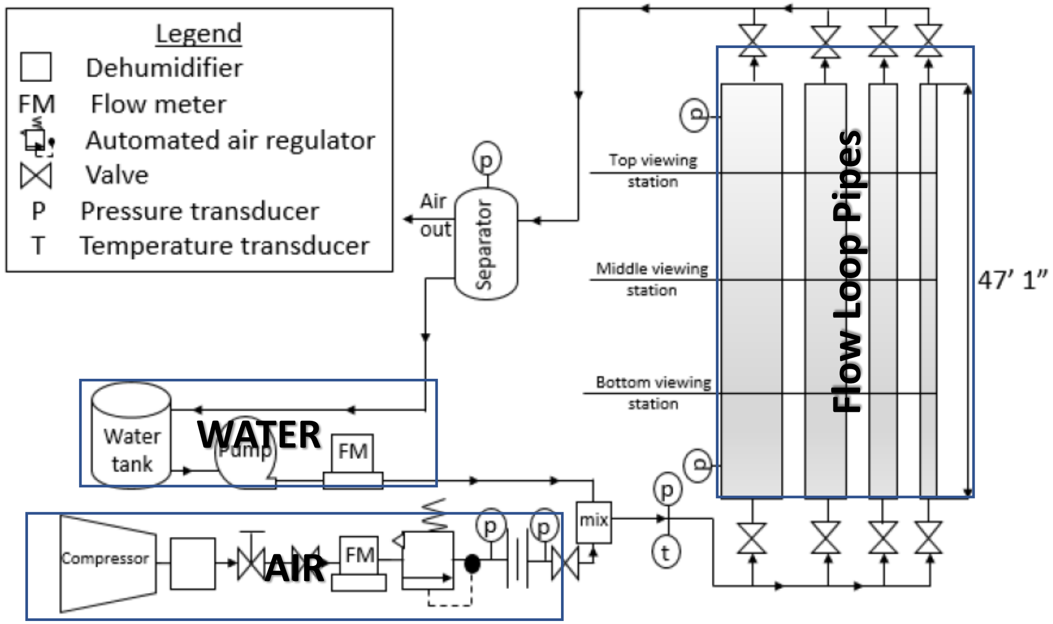
MTVFL

- Four pipe sizes (2”, 1”, 0.75” & 0.5”)
- Air and water as proxies for gas and oil
    - Air rate range: 9-90 scfm
    - Water rate range: 2-20 gpm
    - These rates are for Malin’s work
- Visually observe flow through transparent pipes
- Measure air and water rates, and inlet and outlet pressure



Schematic of MTVFL

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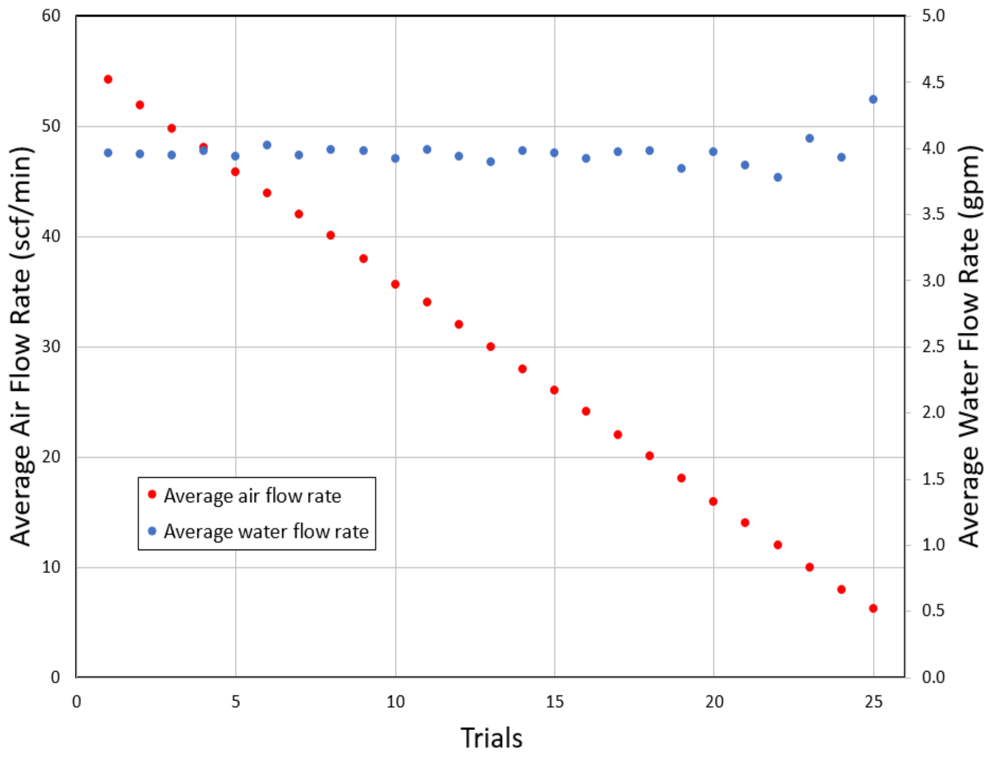
Key Points from Malin’s work

Flow experiments in MTVFL

- Ran Flow experiments over a range of air and water rates
- Conducted experiments in 2” and 1” flow tubes
- Visual observations of the flow behavior
- Development of “Flow Morphology Matrix”



Average air & water flow data for 25 trials of the 1.0’’ flow experiments (ref. Mat Malin)

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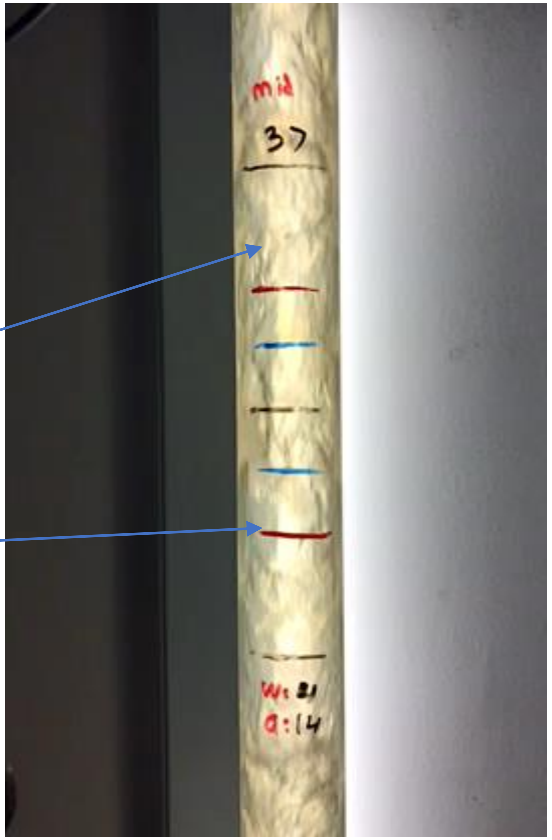
Flow Morphology Matrix

Liquid Film Intensity Morphology Matrix

Morphology Ranking		Liquid Slug Length
1		no liquid slugs
2		Initial bridging, incomplete slug formation
3	a	less than 3"
	b	between 3" – 3"
	c	between 6" – 12"
	d	between 12" – 24"
	e	between 24" – 36"
	f	greater than 36"

Liquid Film Intensity Rating : 3bc

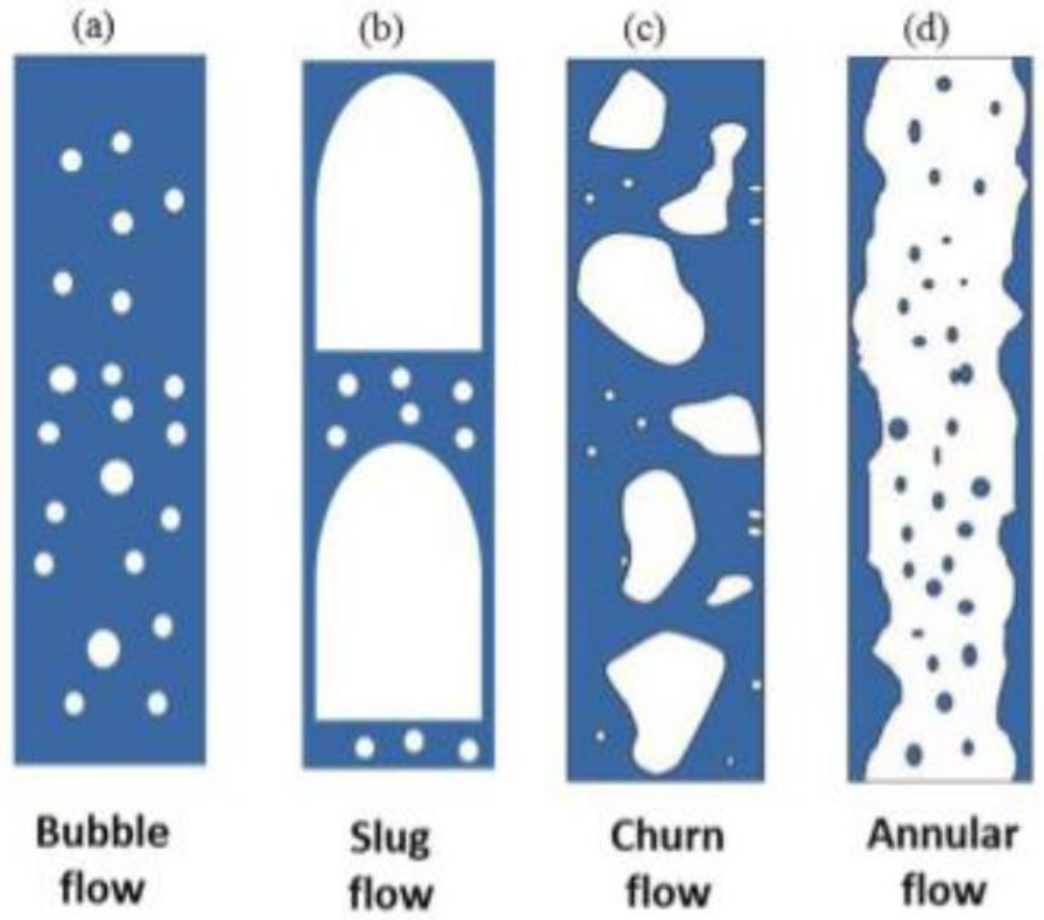
(This analysis was performed for a total of 62 Flow experiments)



Visual of a flow experiment trial, 14 scfm air, 4 gpm water

Flow Regime Maps

- Malin subdivided his flow morphology matrix according to these flow regimes
- Four flow regimes that the flow morphology matrix aims to identify
- Bubble, Slug, Churn, and Annular
- Liquid loading starts to happen transitioning from annular flow to churn flow



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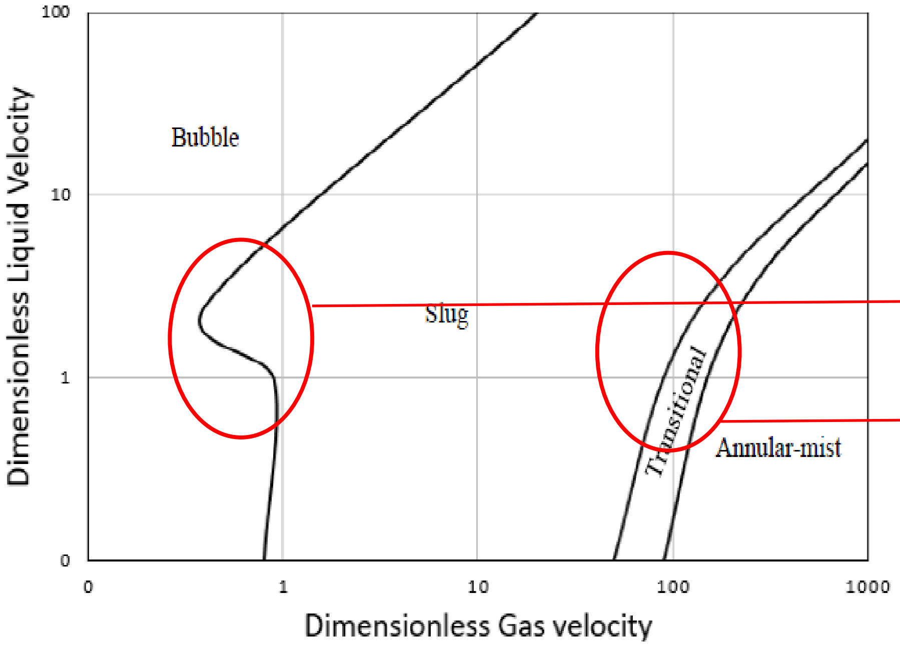
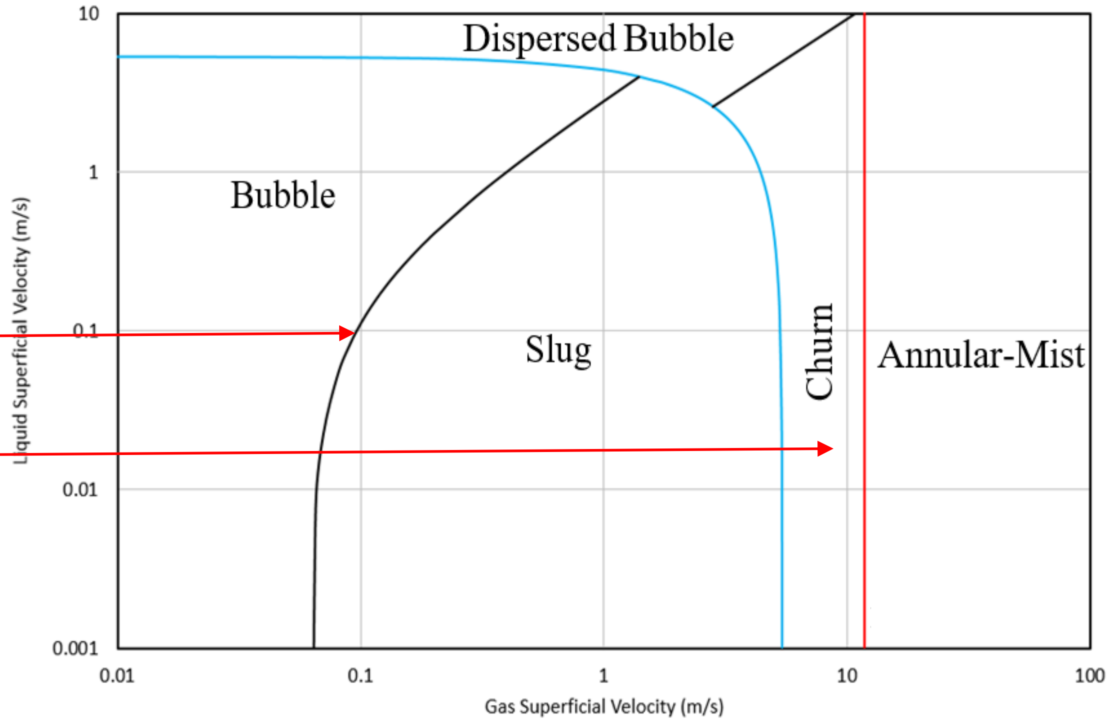
Flow Regime Maps



Orkiszewski's flow regime map



Wu et al. (2017) flow regime map for 2'' tubing

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Transition in Flow Patterns

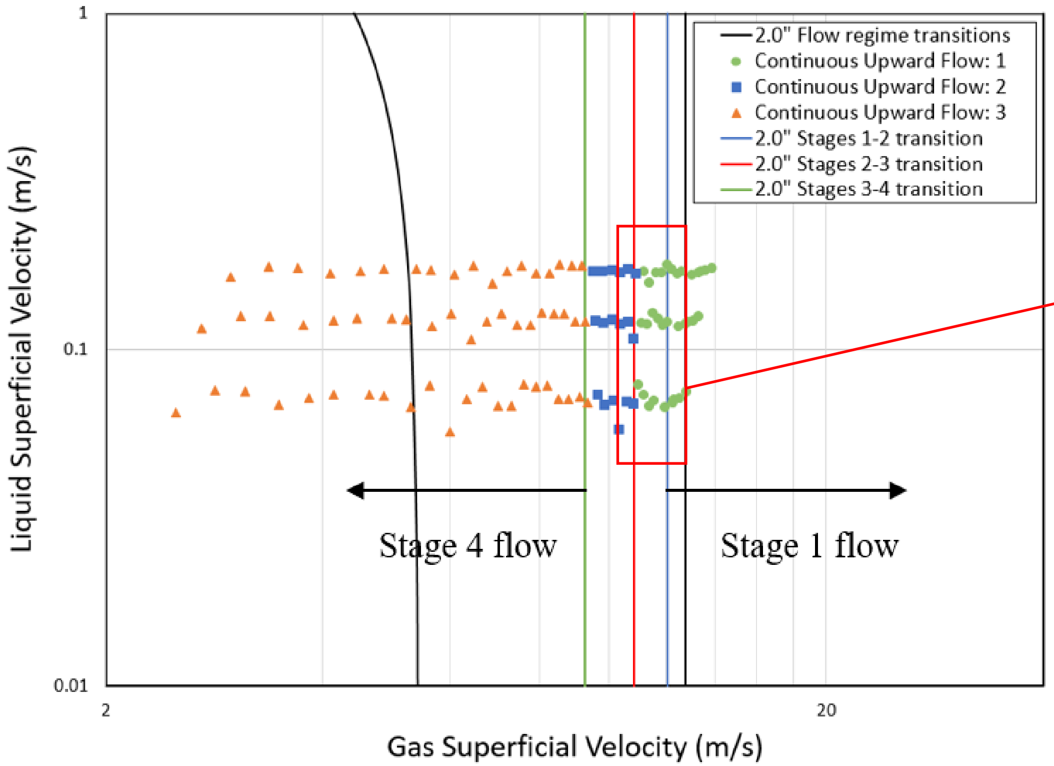

Figure: 2'' Continuous upward flow data with 4-stage flow behavior progression

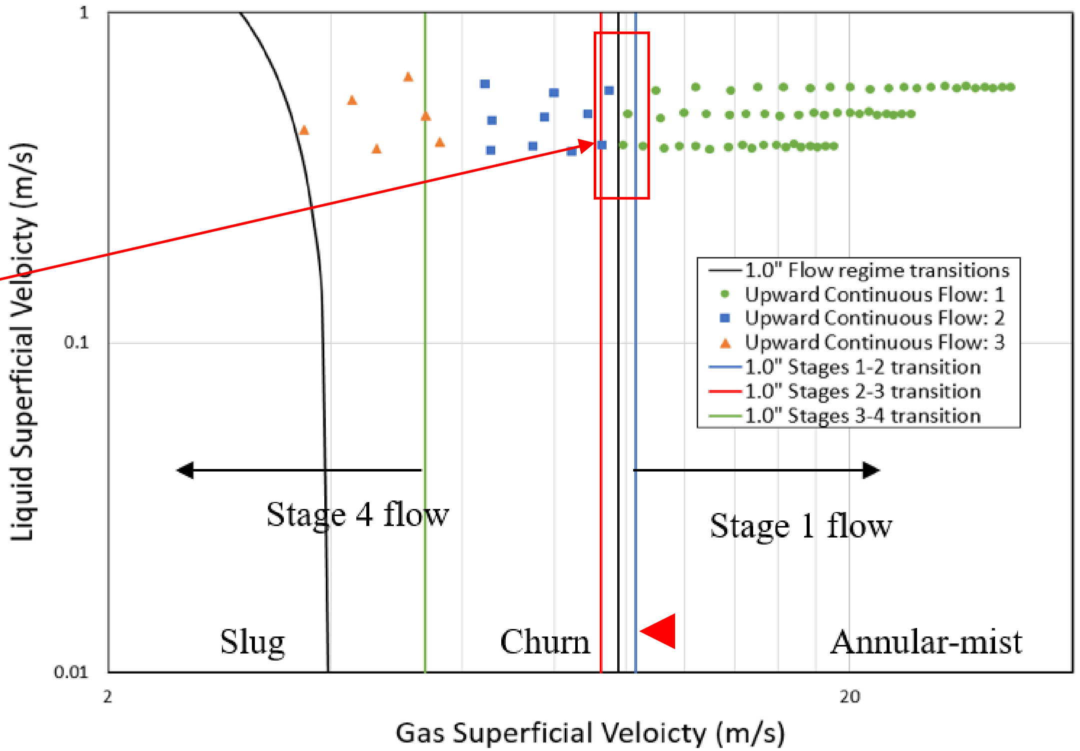

Figure: 1'' Continuous upward flow data with 4-stage flow behavior progression

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Summary of Malin's Findings

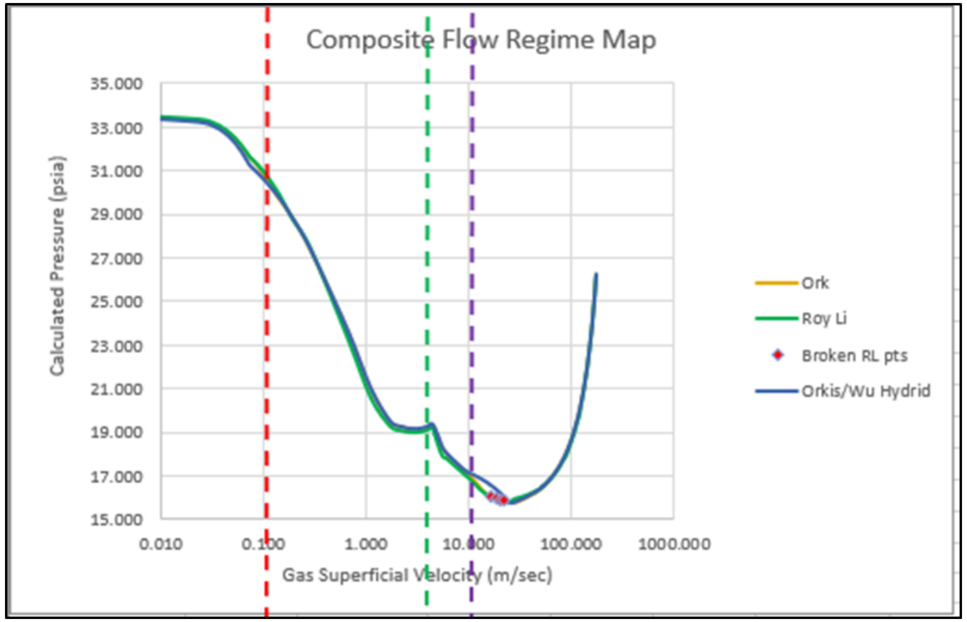
- Liquid loading in small pipes occurs during the transition from annular-mist to churn flow.
- The Annular-Mist/Churn boundary location depends on tubing ID for diameters less than 2.0".
- Long liquid slugs were observed in the 1.0" pipe even during Annular-Mist flow.
- The Turner velocity model isn't accurate for pipe diameters below 2.0".
- Malin's research identified limitations in the MTVFL that need correction for future research.
- Visually observing flow in transparent pipes is challenging and labor-intensive.

MTVFL Enhancements

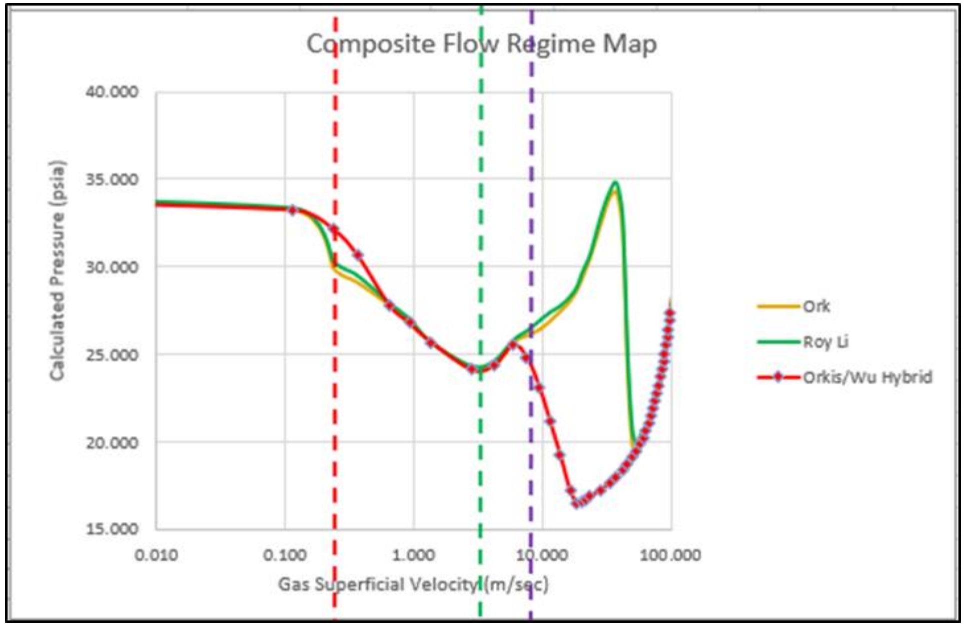
- MTVFL is useful for undergraduate lab observations
- Air rates were excessively high
  - Malin's Air Rate Range → 9 – 90 scfm
  - New Air Rate Range → 6 – 60 scfm
- Water rates were excessively high
  - Malin's water Rate Range → 8 – 80 gpm
  - New water Rate Range → 2 – 20 gpm
- Better valve action when switching between tubing sizes

Goals of Future Research

- If the annular-mist/churn flow regime boundary is a function of tubing size, does this not explain why standard multiphase flow correlations struggle to predict performance of small-diameter pipes?



Comparison of Orkiszewski FR map with Orkiszewski/Wu Hybrid model – 2.0" Tubing



Comparison of Orkiszewski FR map with Orkiszewski/Wu Hybrid model – 1.0" Tubing

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Goals of Future Research

- Malin observed long liquid slugs in 1.0” pipe, even during Annular-Mist flow
  - Small tubing diameter promotes bridging and slugging
  - Classic multiphase flow theory says these slugs should not exist
  - Their presence may help explain the effectiveness of small diameter pipes in liquid removal
  - How can we best exploit this behavior?

- Malin observed a different character of flow changing from 2.0” to 1.0” pipe
  - Do these trends extend into flow in 0.75” and 0.5” pipes?
  - Do these trends become more exaggerated, or do they stabilize?

Personal Research Focus

Present

- Perform test runs with new air handler and water pump
  - Verification of air & water rates
- Re-calibration of the flow loop
- Define current capacity of the MTVFL
  - Maximum and minimum air and water rates
  - For each tubing size
- Test valves to access the 0.75” and 0.5” pipes

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Personal Research Focus

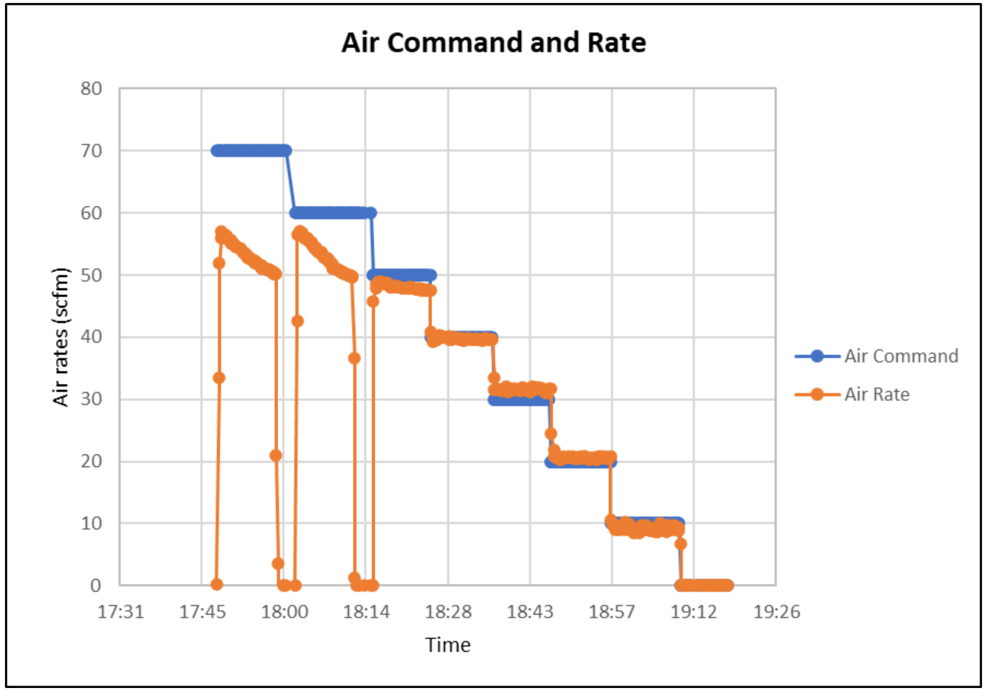
Future

- Literature Review
  - Evaluate flow boundary conditions from peer-reviewed journals
  - Focus on the high-gas rate side of the Flow Regime Map
- Determine the rate ranges we can cover for each pipe size
  - Based on this result, determine which of the Future Research Goals we can address with the current MTVFL configuration
- Determine air rates and water rates needed to evaluate all of the Future Research Goals
  - This will lead to future enhancement recommendations

Verification Runs

Air rate

- Stable air rate from 8 scfm – 50 scfm
- Air rate maxes out at 60 scfm
- At higher air command actual air rates gradually fall, but short periods of shut-off and start-up can again give rise to threshold maximum value



Air command & rates for 10 gpm of water

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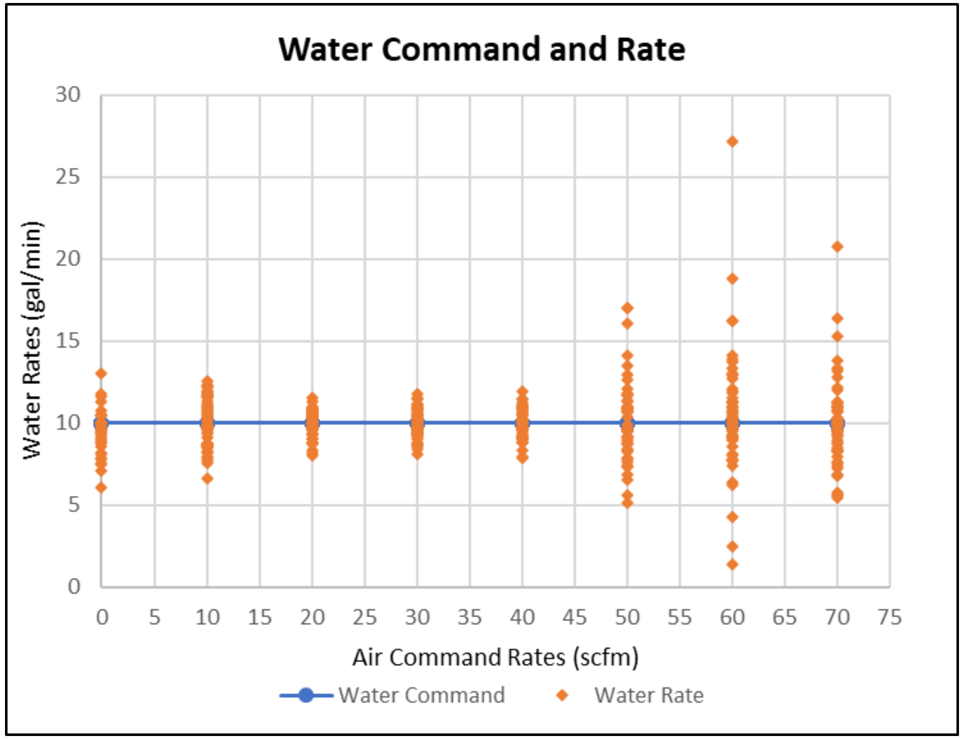
Verification Runs

Water rate

- Water rate fluctuates at lower and higher air command rates
- Water rates show stabilization at medium air command rates
- This observation is for mixed air-water flow rates
- General capacity of water pump 2 gpm – 20 gpm



Water command & rates for mixed air-water flow

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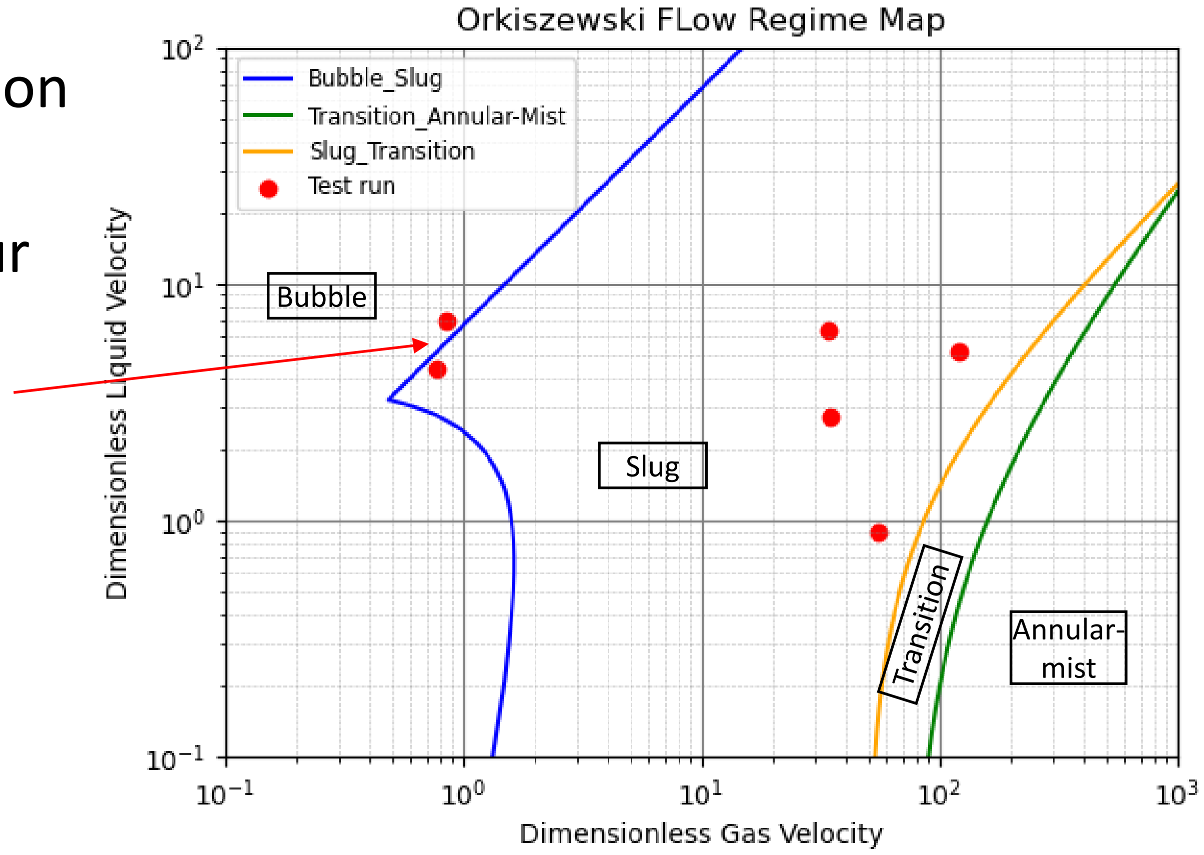
Verification Runs

- Test calculation of flow loop run
- Comparison between our observation & Orkiszewski's map
- Data points at Bubble slug prove our verification of air rates (at low air commands pump shows unrealistic results)

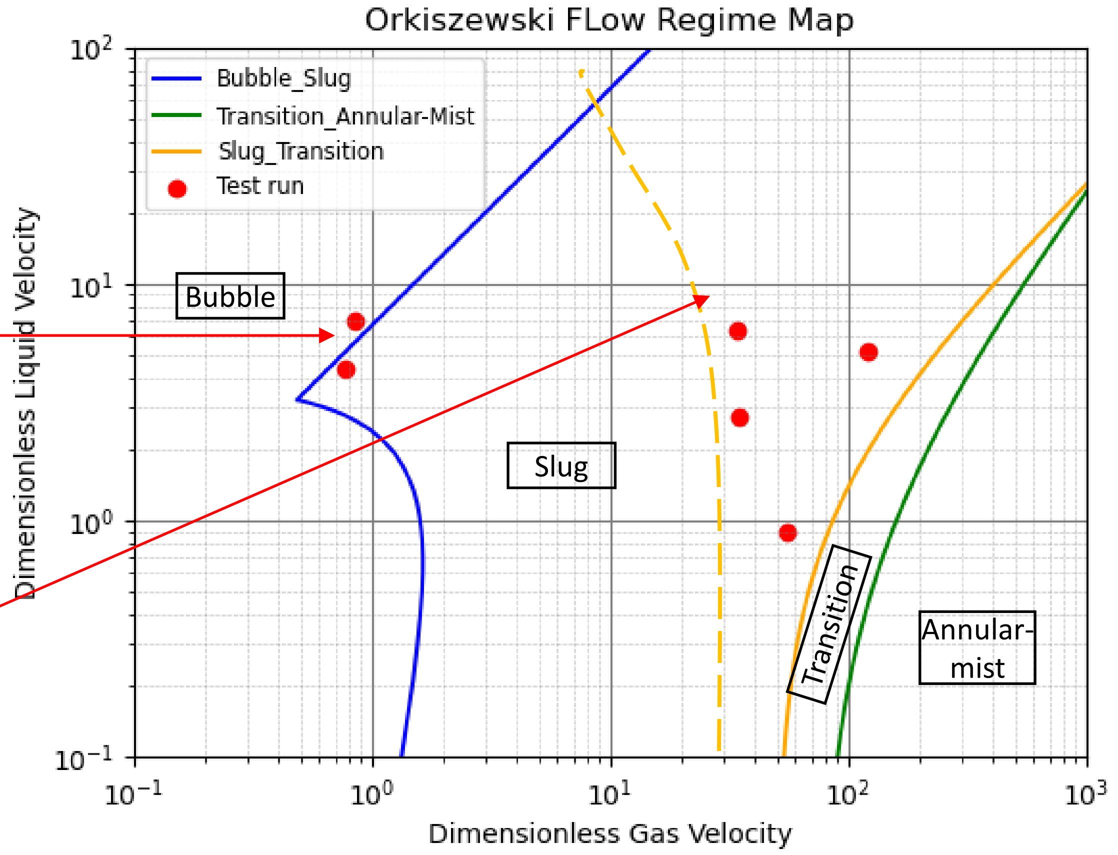


Verification Runs

- Low air rates fall at the bubble/slug

Trial	Actual rates (average)	Dimensionless gas velocity, V_{gD}	Dimensionless water velocity, V_{lD}	Orikisweszki equation regime	Visually observed regime
2 gpm, 15 scfm	1.74 gpm, 14.40 scfm	55.453	0.896	Slug	Transition/churn
6 gpm, 10 scfm	5.28 gpm, 8.93 scfm	34.389	2.718	Slug	Transition/churn
9 gpm, 5 scfm	8.49 gpm, 0.20 scfm	0.770	4.371	Slug	Transition/churn
15 gpm, 3 scfm	13.63 gpm, 0.22 scfm	0.847	7.017	Bubble	Transition/churn
12 gpm, 10 scfm	12.31 gpm, 8.85 scfm	34.081	6.337	Slug	Transition/churn
10 gpm, 30scfm	10.13 gpm, 31.44 scfm	121.072	5.215	Slug	Transition/churn

debatable, other researchers (Wu et al, Taitel et al, etc.) suggest different boundaries. (Boundary not exact to scale).



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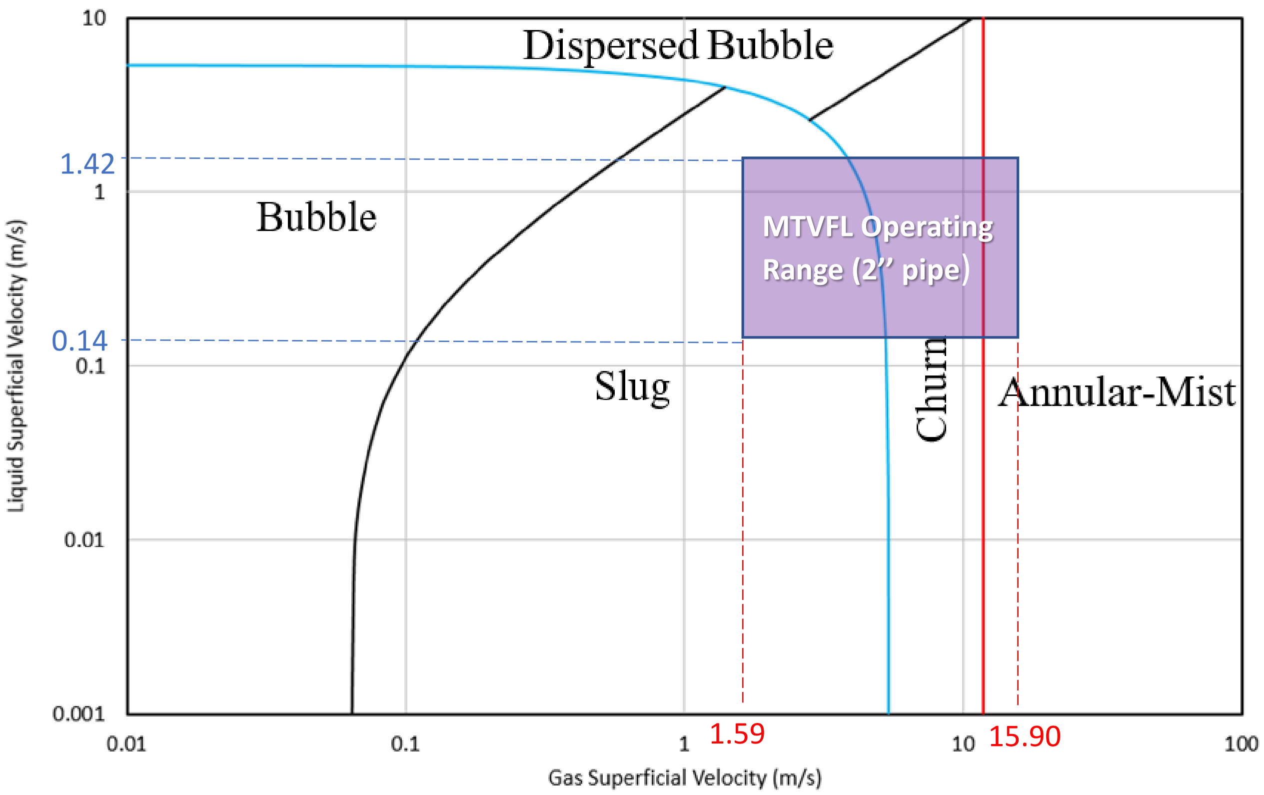
Operating Range – 2.0” pipe

- Without our current MTVFL capacity we can operate in this range.
- But this range could shift rightwards (Annular-Mist region) if we operate in 1’’ pipe (reference: Mat Malin)

Gas rate	
ft3/min (scfm)	m/s
6	1.59
60	15.90
Water rate	
gpm	m/s
4	0.14
40	1.42



Wu et al. (2017) flow regime map for 2’’ tubing

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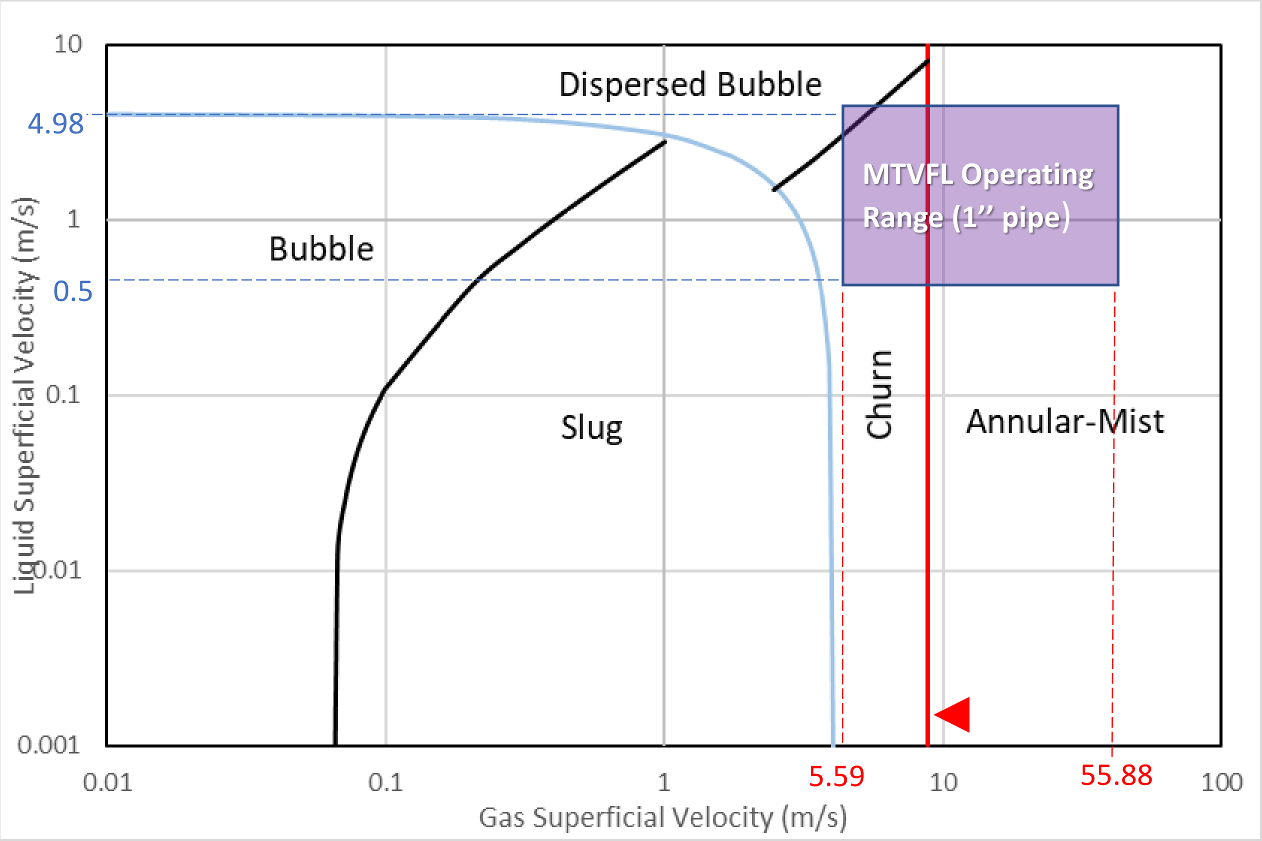
Operating Range – 1.0” pipe

- Without our current MTVFL capacity we can operate in this range.
- But this range could shift rightwards (Annular-Mist region) if we operate in 1’’ pipe (reference: Mat Malin)

Gas rate	
ft3/min (scfm)	m/s
6	5.59
60	55.88
Water rate	
gpm	m/s
4	0.50
40	4.98



Wu et al. (2017) flow regime map for 1’’ tubing

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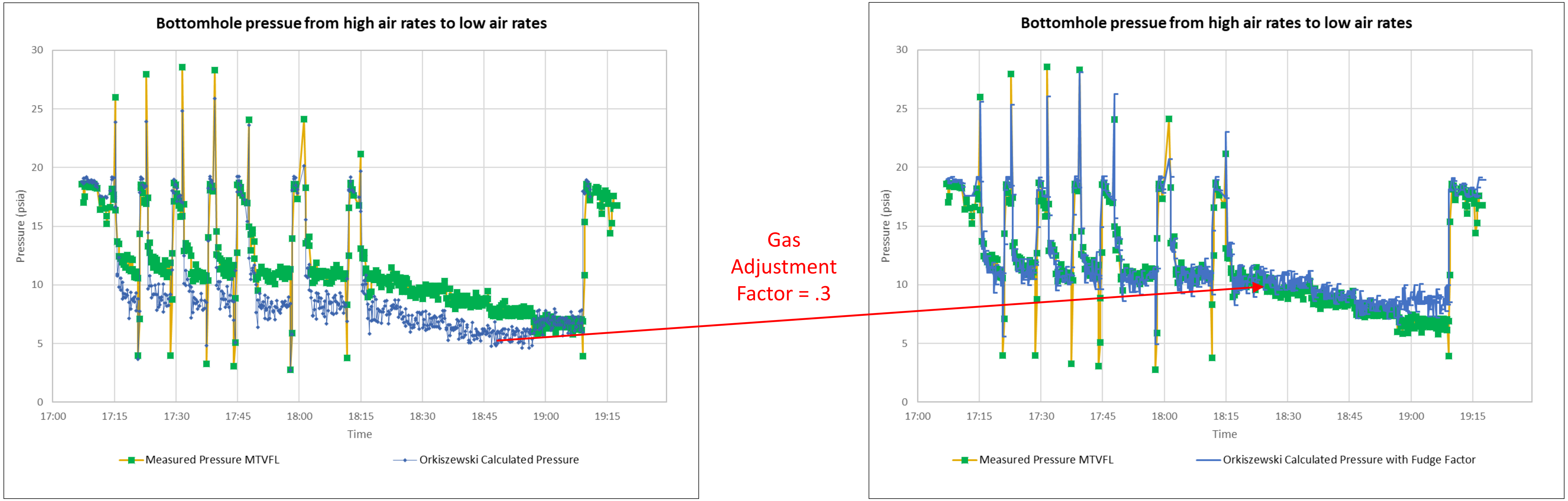
Air Handler Calibration



- Pressures calculated by Orkiszewski systematically lower than measured
- If gas rate is multiplied by 0.3, the pressure match is nearly perfect
- Indicates gas rates from new air handler not properly calibrated

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Air Handler PLC Code

Name	Alias	Data Type	Dimension	Project Value	Initial Value	Comment	String Size
DO_Int_Cont_19		BOOL		FALSE			
FlowControlValveComma		REAL		1.0	0.0		
FlowOrficeMax		REAL		200.0	200.0		
FlowOrficeMin		REAL		0.0	0.0		
FlwLoop1HighAlarm	Flow Loop 1 Pressure Hi(	BOOL		FALSE			
FlwLoop1HighHighAlarm	Flow Loop 1 Pressure Cri	BOOL		FALSE			
FlwLoop2HighAlarm	Flow Loop 2 Pressure Hi(	BOOL		FALSE			
FlwLoop2HighHighAlarm	Flow Loop 2 Pressure Cri	BOOL		FALSE			
FlwLoop3HighAlarm	Flow Loop 3 Pressure Hi(	BOOL		FALSE			
FlwLoop3HighHighAlarm	Flow Loop 3 Pressure Cri	BOOL		FALSE			
FlwLoop4HighAlarm	Flow Loop 4 Pressure Hi(	BOOL		FALSE			
FlwLoop4HighHighAlarm	Flow Loop 4 Pressure Cri	BOOL		FALSE			

- PLC code analysis
- Identify variables that can be modified to calibrate flow rates

Near-Term Tasks

- Finish Recalibrating the Flow Loop, Revising PLC code as necessary
- Implement advanced verification techniques for air and water flow rates
- Verify functionality of Valving/Flow tube switching controls
- Determine the applicable range for conducting tests within the current MTVFL configuration

Near-Term Tasks

- Isolate specific test question(s)
- Evaluate those questions by
  - Measuring flow properties with the MTVFL
  - Compare measured results with the Orkiszewski flow correlation
  - Make enhancements as needed
- Present these results next year at the 30th Montana Tech SPE Symposium!!

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Acknowledgements

- Professor Dr Burt Todd
- Professor David Rathgeber

Questions?

Thank you for your time and attention

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