

Contents

1.	Chapter 1: Introduction.....	1
2.	Chapter 2: Background.....	4
2.1.	Electrostatic potential as an additional bifurcation variable.....	4
2.2.	Chaos & feedback control.....	8
2.2.1.	Concepts of chaos.....	9
2.2.2.	OGY control.....	13
2.3.	Summary.....	20
3.	Chapter 3: Methods	22
3.1.	Experimental.....	22
3.1.1.	Introduction.....	22
3.1.2.	Set-up Details.....	23
3.1.2.1.	The glass column.....	23
3.1.2.2.	Gas flow and metering system.....	25

3.1.2.3.	Liquid selection.....	27
3.1.2.4.	Data acquisition system.....	28
3.1.2.5.	Nozzle construction.....	28
3.1.3.	Procedure.....	30
3.2.	Data analysis.....	31
3.2.1.	Power spectra.....	31
3.2.2.	Bifurcation and route to chaos.....	32
3.2.3.	Time return maps.....	32
3.2.4.	Phase space reconstruction.....	33
3.2.5.	Multivariate statistical techniques.....	33
3.2.6.	Neural network model for regime identification.....	35
4.	Chapter 4: Observations and analysis.....	37
4.1.	Formation of a single bubble.....	37
4.2.	Regimes of bubbling.....	40
4.2.1.	Period-1 bubbling.....	42
4.2.2.	Period-2 bubbling.....	45
4.2.3.	Period-4 bubbling.....	49
4.2.4.	Chaotic bubbling.....	52
4.3.	Effect of electrostatic potential on bubbling.....	54

4.3.1.	Pressure traces.....	54
4.3.2.	Periods of formation.....	56
4.3.3.	Time return maps.....	59
4.3.4.	Phase space analysis.....	65
4.3.5.	Power spectrum distribution.....	65
4.3.6.	Bifurcation diagram.....	65
4.3.6.1.	Bifurcation at constant voltage.....	68
4.3.6.2.	Bifurcation with voltage and flow.....	68
4.3.7.	Bubbling regimes in terms of dimensionless numbers.....	70
5.	Application & Implementation.....	78
5.1.	Periodicity identification.....	78
5.1.1.	Statistical modeling.....	79
5.1.2.	Neural network models.....	79
5.1.3.	Periodicity pattern detector.....	81
5.2.	Regime targeting of bubbling with electrostatic potential.....	83
5.3.	OGY Control.....	90
5.3.1.	Calculations.....	90
5.3.1.1.	Identifying the unstable fixed point	91

5.3.1.2.	Calculating the manifolds.....	91
5.3.1.3.	Calculating the eigenvalues.....	94
5.3.1.4.	Shift vector.....	96
5.3.2.	Results	96
5.3.3.	Entrainment studies.....	99
5.4.	Summary.....	104
6.	Conclusions & recommendations	105
	References.....	108
	Appendices.....	113
	Appendix A: Progressive time return maps at constant flow rate and increasing electrostatic potential for a representative data set.....	114
	Appendix B: Screen shot of the Bubble Toolbox for Chaotic Analysis.....	125
	Appendix C: Screenshot of the Automation Workbench for Labview.....	126
	Appendix D. Rotameter calibration curve at 10psig.....	127
	Appendix E: Nomenclature.....	128
	Vita.....	129