Chapter 1

# Introduction

*In all chaos there is a cosmos, in all disorder a secret order*
Carl Jung

Effervescence and bubbling have always been thought of as one of the simple phenomena, which make life interesting to look at. But beneath this innocuous visage lies a system so complex that the last decade has produced a flurry of papers investigating the interplay of bubbles. From numerical modeling of bubbles to studying the effect of sounds of bubble formation, numerous research thrusts have been made to try and capture this phenomenon in its entirety. Control of bubbles is one such aspect. Several attempts have been made to control bubbles, to tame them from a spectrum of sizes to a single file of pearls. But till date no successful attempts have been reported not only because of the spatio-temporal behavior, but also the sensitivity of the bubbling experiments to external noise. Yet it is the same simplicity of the experimental arrangements with bubbling experiments, which have made chaotic analysis through bubbles a favorite. It is certainly easier to study chaos in a bubble column than to simulate it in earthquakes!

This research was carried out with two objectives:

1. To identify a new control variable for bubbling
2. To tame chaos in bubbling by using the new control variable

These were two disjoint research directions. The first involved understanding the bubbling from the fluid mechanics point of view and studying the dynamics associated with the system. Once the system was quantified in terms of bubbling regimes and dimensionless numbers, the next step was to integrate the system information with control equations and set-up a schemes to implement the control. The latter phase of implementing the control algorithm was the most challenging. And it is this phase, where previous experience had showed, maximum investment was to be made.

Data acquisition and automation techniques were employed to generate large volumes of data for study. For the characterization studies of the bubble system, data analysis tools were built for data mining from the experimental data sets. Development of data analysis tools spurred study of statistical techniques like principal component analysis and wavelets to the bubbling data. Finally, to employ the control algorithm, real time computing modules were built for online analytical processing and simultaneous control. All of the software tools built for this experiment were in conjunction with Oak Ridge National Laboratory (ORNL) and are available through ORNL for evaluation. The reader is encouraged to contact the Duane D. Bruns research group at the University of Tennessee, Knoxville for an evaluation copy of the BUBBLE Toolbox for Chaotic Analysis© (Sarnobat, 2000) and the BUBBLE Automation Workbench© (Sarnobat, 2000) along with sample data for research purposes.

This research project has been documented in three parts, one as a part of this Master's thesis, a second as research papers submitted at the University of Tennessee, Knoxville and third as software releases through Oak Ridge National Laboratory.

In the present thesis, the first chapter gives an introduction to the overall project. The second chapter updates the reader with concepts from research in bubbles and chaos control. The third chapter describes the experimental and data analysis techniques used. The fourth chapter presents the results and analysis from the identification of the bubbling system. The fifth chapter has results from the attempt to control chaos by using a well-known control algorithm. The sixth and final chapter details the conclusions and recommendations.