ZIN Technologies
PHi Engineering Support

PHi-RPT-0002

CFD Analysis of
Large Bubble Mixing

June 26, 2006

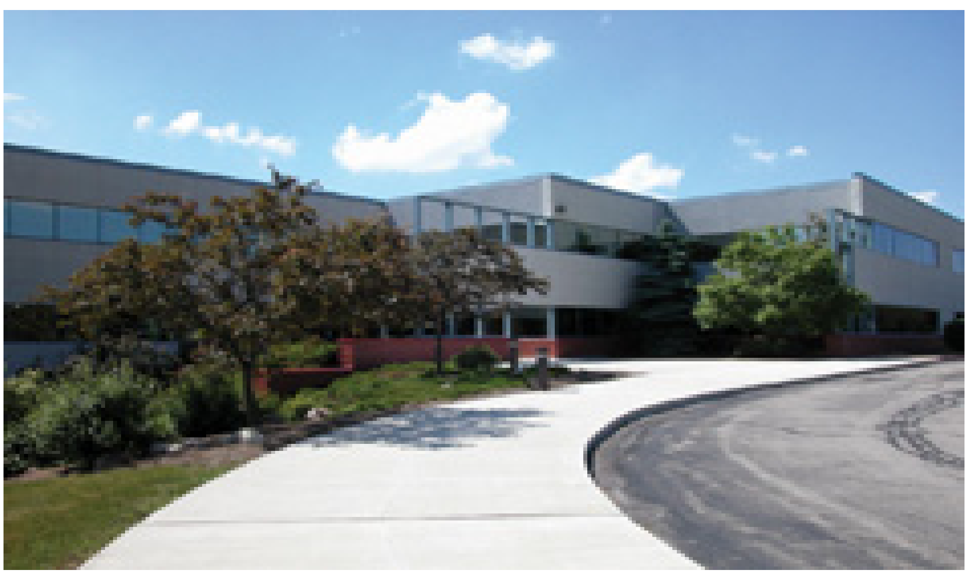
ZIN Technologies

Proprietary

ZIN Technologies, Inc.

For nearly five decades, ZIN Technologies has provided integrated products and spaceflight hardware development services to NASA and Fortune 500 companies. ZIN-Tech specializes in the seamless and transparent progression between concept, detailed design, engineering, manufacturing, and operations. ZIN-Tech, with its uniquely qualified staff, and a proven track record of award winning work, delivers product development, system prototypes, and space flight hardware on time and under budget. ZIN-Tech has many scientists, engineers, and technicians engaged in the development of specialized data acquisition and control systems, power converters, and optical-mechanical systems for aerospace and commercial applications.

ZIN-Tech experience base includes competitively awarded engineering contracts from both government and commercial companies. Our scope of experience includes scientific, technical, operational, and program management, as well as the disciplines associated with large, complex space programs. To successfully accomplished quality standards and customer requirements ZIN Technologies has three divisions: NASA, DOD/Commercial and Power. Each division is managed by professionals with outstanding knowledge and valuable experience in their areas.



Approvals

Prepared by: Dr. William A. Arnold Date: 6/26/06

Dr. William A. Arnold, Ph.D.
Interdisciplinary Engineer / Scientist
ZIN Technologies, Inc.

Concurred by: Dr. Carlos Grodsinsky Date: 6/26/06

Dr. Carlos M. Grodsinsky, Ph.D.
Vice President – Technology
ZIN Technologies, Inc.

Accepted by: ____________________ Date: ________

Kris Drewry
Pulsed Hydraulics, Inc.

Revisions

Revision Letter	Description	Release Date
-	**Final**	**06/26/06**

Table of Contents

1 INTRODUCTION AND BACKGROUND 5
1.1 Wastewater Mixing Needs.....5
1.2 Current Mixing Methodologies 5
1.3 PHi Design 5

2 PURPOSE 6

3 COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSES 7
3.1 Application of 2D Axi-symmetric analysis to 3D Geometry 7
3.2 CFD Code.....7
3.3 CFD Model and Boundary Conditions.....8
3.4 CFD Results 9

4 CONCLUSIONS AND DISCUSSION 13

5 REFERENCES.....13

List of Figures

FIGURE 1. HYDRO-PULSE BUBBLE FORMING PLATES AT THE BOTTOM OF TANK.....6
FIGURE 2. PICTORIAL OF A 22.5' X 110' TANK WITH 5 PHI FORMING PLATES INSTALLED. 7
FIGURE 3. THE CFD MODEL AND MESH FOR A LARGE BUBBLE RISING IN A CYLINDRICAL TANK. 8
FIGURE 4. VELOCITY PLOT (M/S) OF THE MODEL WITH REAL WALL AT R = 4.85 M AT T≈15 MINUTES. 10
FIGURE 5. STREAMLINES OF THE REAL WALL MODEL AT T≈15 MINUTES.....10
FIGURE 6. THE KINETIC ENERGY IN THE TANK AS A FUNCTION OF TIME WITH A REAL WALL.....11
FIGURE 7. THE MODEL WITH VIRTUAL WALL. STREAMLINES SHOWN.....12
FIGURE 8. THE KINETIC ENERGY IN THE TANK AS A FUNCTION OF TIME WITH A VIRTUAL WALL. 12

1 Introduction and Background

1.1 Wastewater Mixing Needs

Wastewater treatment typically uses large holding facilities on the order of millions of gallons. Whether operating in aerobic or anaerobic (anoxic) modes, these large water volumes need to be mixed for them to adequately perform their functions. The key is to provide a uniform environment, both chemically and thermally. Thorough mixing provides this homogeneous environment.

1.2 Current Mixing Methodologies

Many mixing technologies have been implemented and used over the past century. These include, but are not limited to, surface, impeller type, and, although not classified as a mixer, small bubble diffusers. These mixers all improve the homogeneity of the mix, since any movement within the water will provide convective mixing. The issue though, is their varying efficiencies and other related drawbacks.

1.3 PHi Design

PHi, Pulsed Hydraulics, Inc., has a mixing device that operates on compressed air http://phiwater.com. The PHi mixing system consists of three basic component groups: compressed air, a Sequencing Computer, and Hydro-Pulse forming plates. Compressed air is supplied through a compressor creating the source of the Hydro-Pulse bubble which mixes the contents of the tank. The Sequencing Computer manages the parameters and schedule of the mixing, controlling the “bubble-pulse” intensity, duration, interval between pulses, and pulsing sequence between different forming plates or groups of forming plates in a tank. Forming plates are constructed from various materials to fit the specific application and are designed to form a Hydro-Pulse, a massive air "bubble" which creates the mixing hydraulics starting from the bottom to the top of the tank. PHi recommends 304 stainless steel forming plates.

Compressed air is pulsed through a forming plate installed on the bottom of the tank, creating a "Hydro-Pulse" wave that captures sediment from the bottom and starts the mixing process. The forming plate's design causes the air to form into a bubble-mass above the forming plate, pulling liquid and sediment from the bottom of the tank. As their literature states, when the bubble begins its ascent, it presses liquids and solids above it upward, and draws liquid and sediment along from beneath. As it continues to rise, liquid and solids in its path are put into motion upward. When the bubble breaks on the surface, the liquid and solids move tangentially to the surface, producing a surface mixing motion that moves to the tank wall and then down the sides to the bottom, completing the mixing cycle. The forming plates are shown in Figure 1.

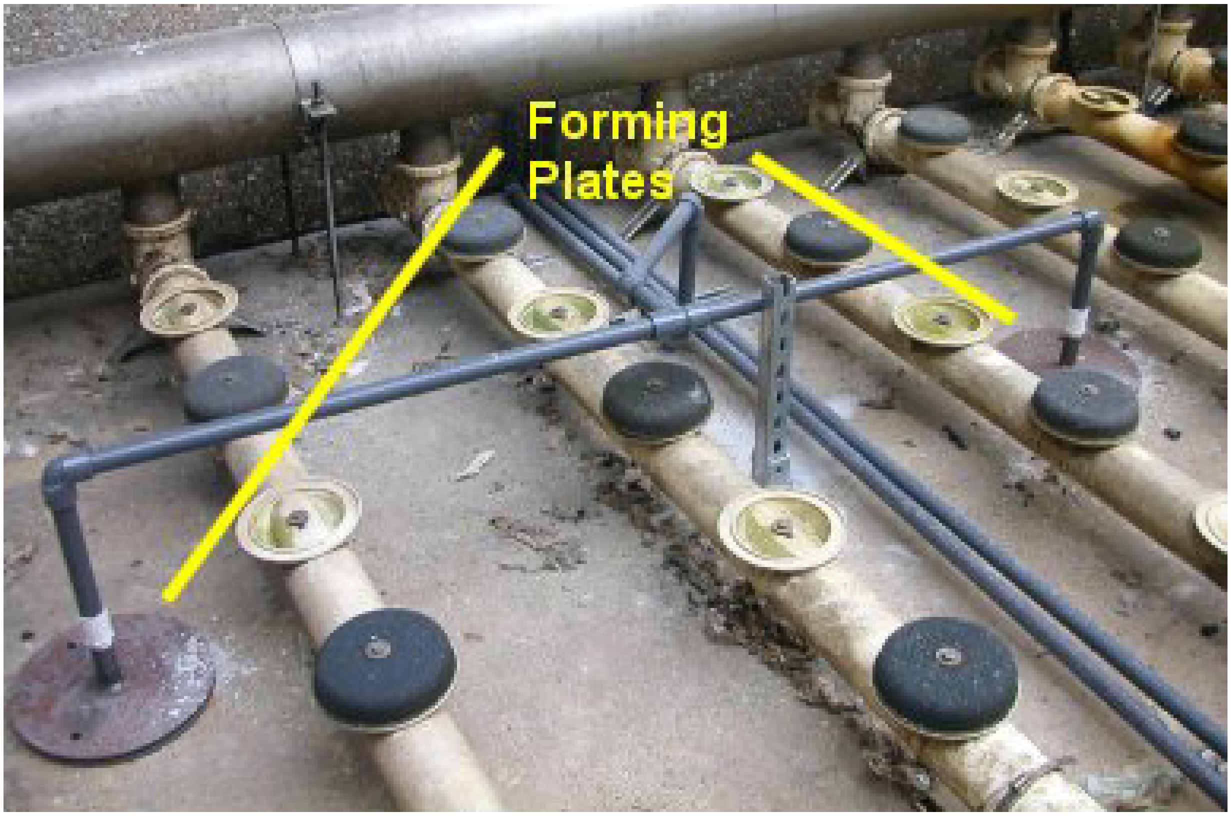


Figure 1. Hydro-Pulse bubble forming plates at the bottom of tank

2 Purpose

The objective of this report is to define mixing criteria in terms of plate spacing of the Phi forming plates and to evaluate its application to the geometry of a specific tank. These design criteria will be used to optimize the convective mixing, eliminate dead-spots, and to determine the time necessary to reach a steady-state. A Computational Fluids Dynamics (CFD) was used in this analysis. These mixing criteria will serve as guidelines for plant installation and design.

3 Computational Fluid Dynamics (CFD) Analyses

3.1 Application of 2D Axi-symmetric analysis to 3D Geometry

A pictorial of the 3D tank with 5 PHi forming plates is shown below in Figure 2. In this configuration there are real walls and virtual walls. Real walls are physical walls, while virtual walls are walls set up by flow symmetry due to geometry and forming plate locations. The virtual walls can be affected by timing of the forming plates. Virtual walls have fluid motion in the "plane" of the wall, but fluid cannot pass through the wall. The worst-case radius (largest distance to a real or virtual wall) is shown in red and is 4.85 m (15.9 feet).

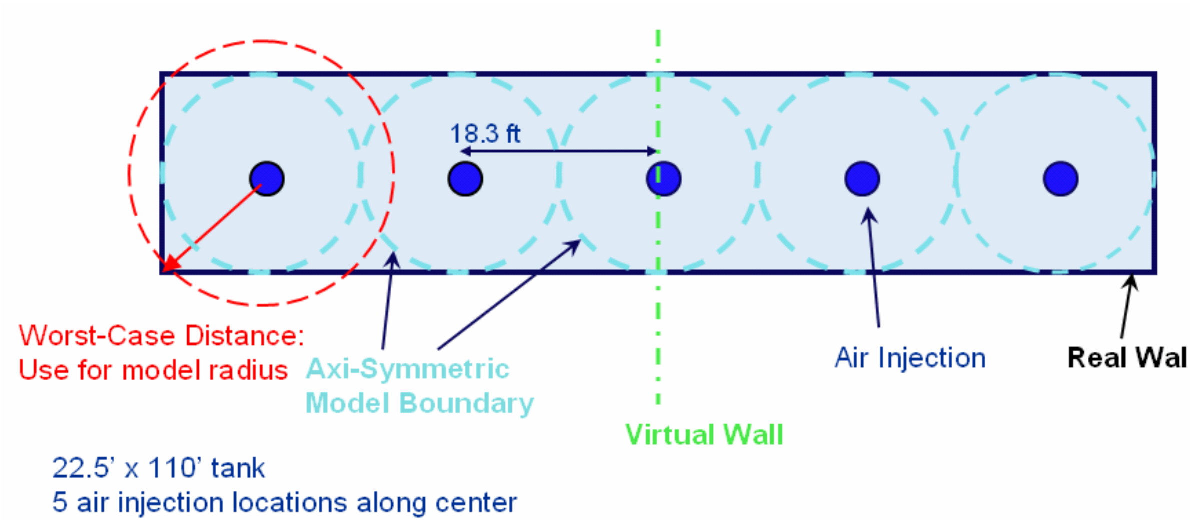


Figure 2. Pictorial of a 22.5' x 110' tank with 5 PHi forming plates installed.

3.2 CFD Code

Computational Fluid Dynamics (CFD) analyses of the rising PHi large bubble was performed using software named COMPACT. COMPACT is a computational fluid dynamics program used to calculate fluid flow, heat & mass transfer, chemical reactions, turbulence and other related processes. The two-dimensional axi-symmetric numerical analyses presented here involved the simultaneous solution of the conservation of mass & momentum equations. These computational analyses resulted in critical design information and provided in-depth insights to physical processes.

3.3 CFD Model and Boundary Conditions

Model

The numerical simulations presented here used a 2D axi-symmetric model. The mesh for the model is shown in Figure 3. The bubble rises along the centerline (r=0). The mesh resolution was 100 elements in radius (the radial direction) and 100 elements in the axial (the height direction). The mesh was staggered toward the centerline (at r = 0). The radius was 4.85 m (15.9 feet) and 6.1 feet in height (20 feet deep).

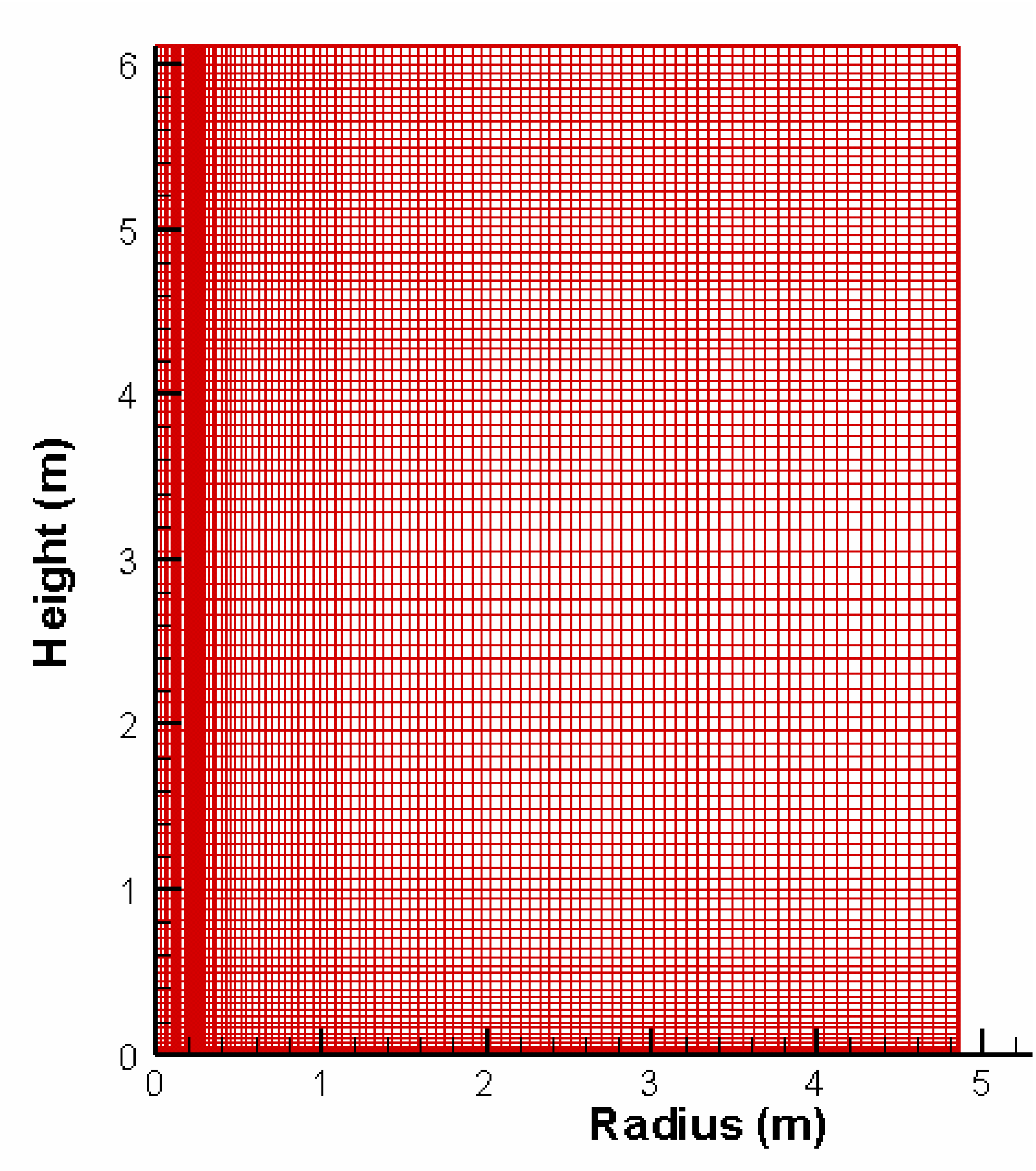


Figure 3. The CFD Model and mesh for a large bubble rising in a cylindrical tank.

Model Boundary Conditions

When a convective cell encounters a physical, or real, wall, the flow in the convection cell flows along the wall but not pass though the wall. The velocity of the fluid at the wall is zero. When symmetry in a tank is encountered, virtual walls can develop. Virtual walls are similar to real walls in that the fluid can not pass through them (normal to the wall). However, a virtual wall does have velocity in the plane of the wall (tangential velocity). The two walls, real and virtual, can be simulated numerically. In a real wall, all velocity components (normal and tangential) are set to zero whereas in a virtual wall, only the normal component is set to zero. Where only the normal velocity component is set to zero, it is also classified as a symmetry boundary condition.

The boundary conditions for the model were:

1. Bottom Wall – Real Wall
2. Centerline Axis, R_{min} – Symmetry
3. Top (air/water interface) – Symmetry
4. Far Wall, R_{max} – Two Cases: (a) Real Wall and (b) Virtual Wall

Rising Large Bubble Implementation

The Rising of a large bubble was implemented via a known rising velocity. The bubble was not formally modeled as a two-phase system, but rather the motion of the bubble and *assumed spherical boundaries* implemented. This velocity was imparted on the spherical bubble rising at a rate of 1.22 m/s (4 feet/s). The velocity was determined via experimental observation measurements of the bubbles by PHi personnel. The COMPACT code was modified to implement this condition in the subroutine ADAPT. A rate of 1 bubble every 20 seconds (3 bubbles per minute) was imposed. The rise time per bubble was approximately 5 seconds.

3.4 CFD Results

Real Wall

The velocity plot of the 2D axi-symmetric model with a real wall at $r = r_{max}$, at t=903 seconds (15+ minutes), is shown in Figure 4. The plot clearly shows the bubble rising along the centerline axis (left-hand boundary). The streamline plot is shown in Figure 5. The bubble rising on the axis of symmetry drives a small cell seen in the streamline plot. The flow rotation of the large cell (right side) is clockwise, rising on the centerline (left-hand side) and descending along the real boundary (right hand side). The small cells generated by the PHi bubble feed the large convection cell which grows in intensity until it reaches a pseudo steady-state.

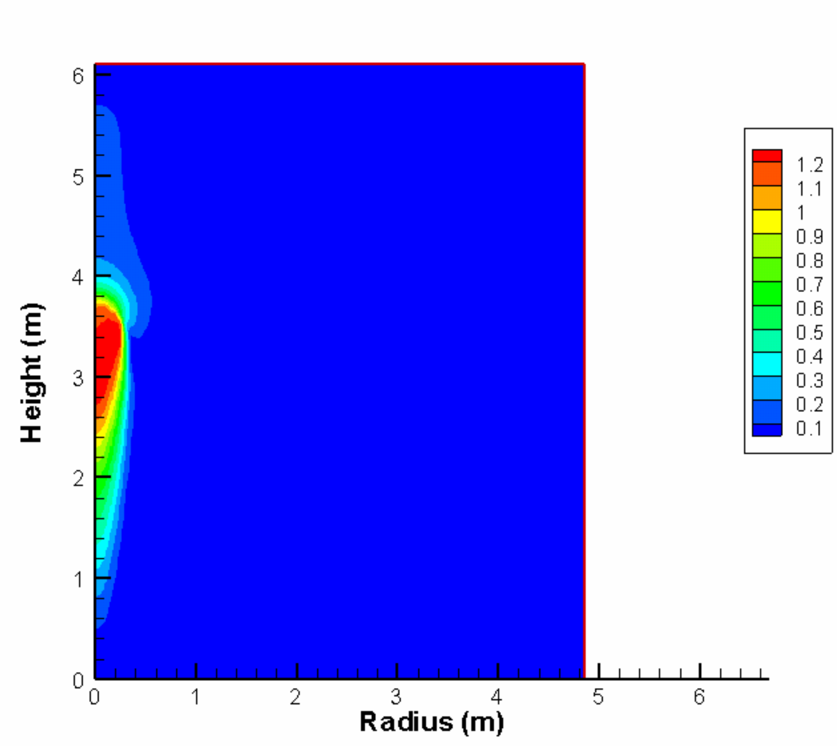


Figure 4. Velocity plot (m/s) of the model with real wall at r = 4.85 m at t≈15 minutes.

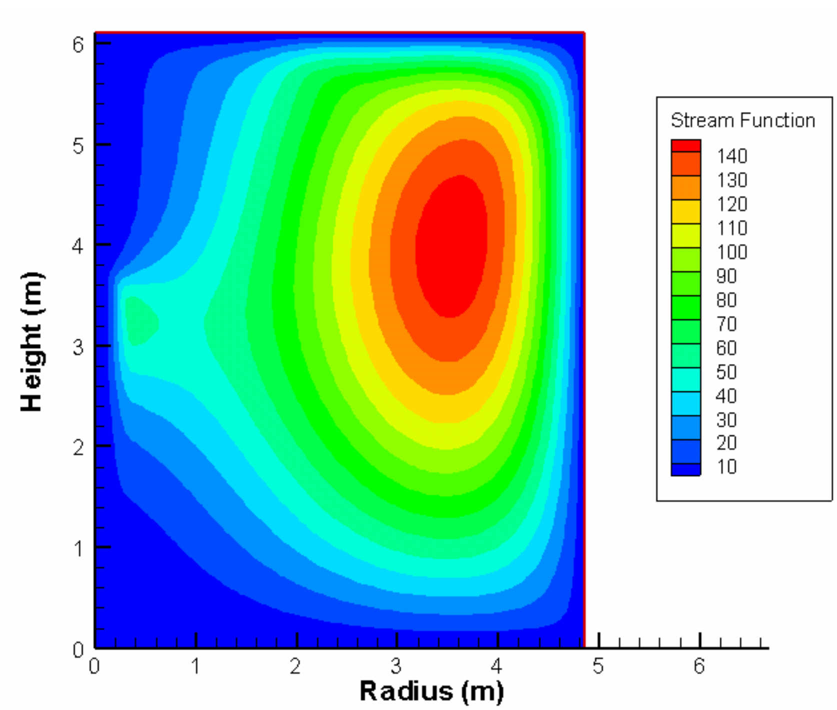


Figure 5. Streamlines of the real wall model at t≈15 minutes.

A plot of the overall, or global, kinetic energy in the tank is shown in Figure 6. The effect of each individual bubble, every 20 seconds, can be seen on the plot. The kinetic energy at 15 minutes (900 s) is approaching a steady-state, but will take about another 15 minutes to achieve.

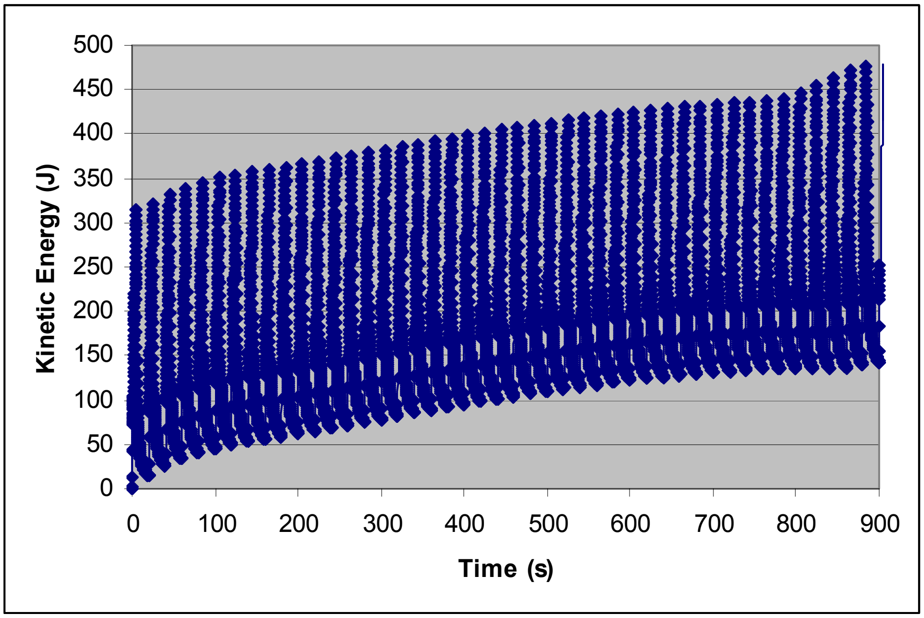


Figure 6. The Kinetic Energy in the tank as a function of time with a real wall.

Virtual Wall

The 2D axi-symmetric streamlines of the model with a virtual wall at $r = r_{max}$ at t= 1803 s (30 minutes) is shown in Figure 7. The flow cell is very similar to the real wall case. Figure 8 shows the Kinetic Energy in the tank. Note that after 600 seconds there is a transition in which the Kinetic Energy decreases then achieves a steady-state at about 30 minutes. The individual bubbles cannot be identified in Figure 8 due to the large number of bubbles in that time period. Thus, the plot appears as a “band” rather than a line plot.

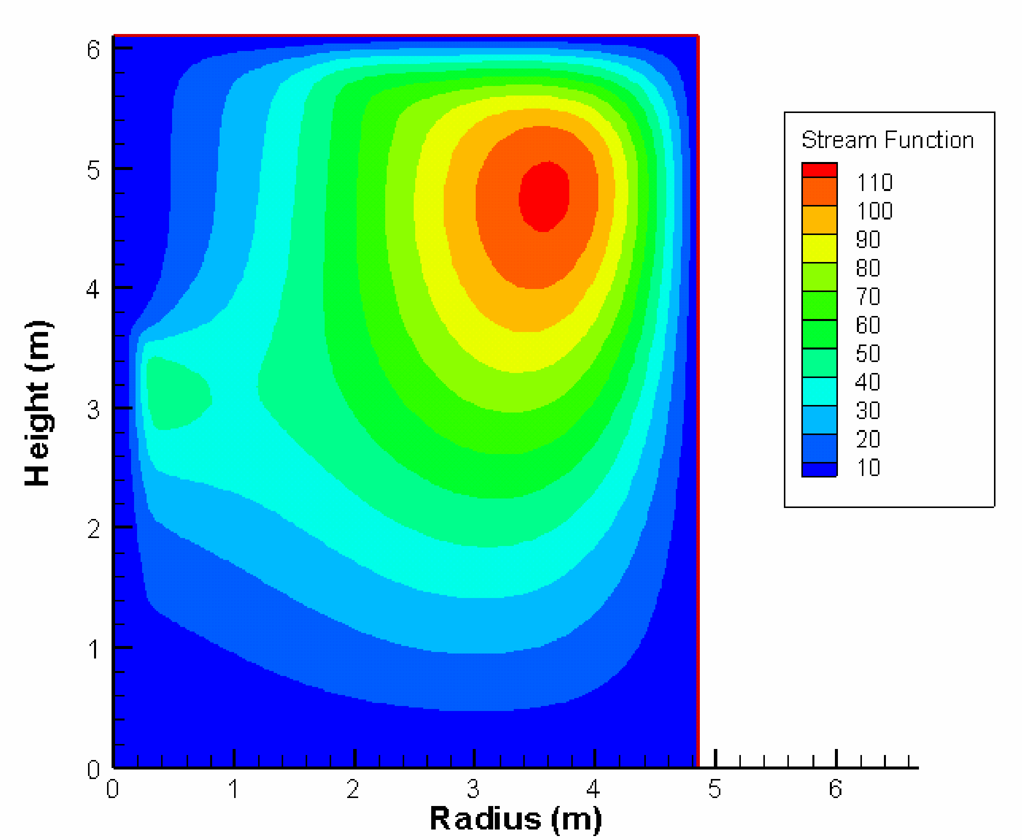


Figure 7. The model with virtual wall. Streamlines shown.

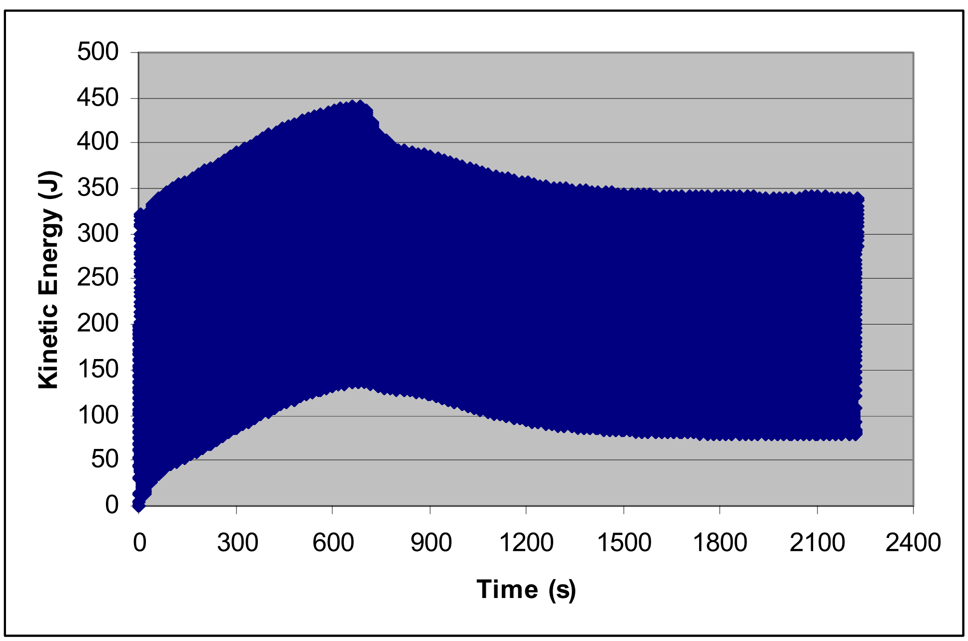


Figure 8. The Kinetic Energy in the tank as a function of time with a virtual wall.

4 Conclusions and Discussion

A 2D axi-symmetric model of the PHi bubble has been developed. The model was run with experimentally measured bubble rise velocity. The model was run with both a real wall and a virtual wall. The radius here represents the worst-case (longest) distance that would be experienced in a mixing tank 22.5 feet in width, 110 feet in length with 5 PHi forming plates installed.

The analyses with real and virtual walls were very similar. The analyses showed that the rising bubbles drive a large recirculation cell. The cell in this model had a Height/radius aspect ratio of 1.26. It is desirable to maintain roughly an aspect ratio of 1 to insure the recirculation cell reaches all portions of the tank. The time to reach pseudo steady-state mixing is approximately 30 minutes.

5 References

1. Incropera & Dewitt, "Fundamentals of Heat and Mass Transfer", Third Edition, John Wiley & Sons, 1990.