# Problem #8

# Bubbles

Team
Korea

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# Problem Objectives

## Problem Statement

Is it possible to float on water when there are a large number of bubbles present? Study how the buoyancy of an object depends on the presence of bubbles.

**1. Buoyancy and Bubbles?**

**2. Is it possible to float?**

# Buoyant Force

in the presence of

# Bubbles

# What is Buoyancy?

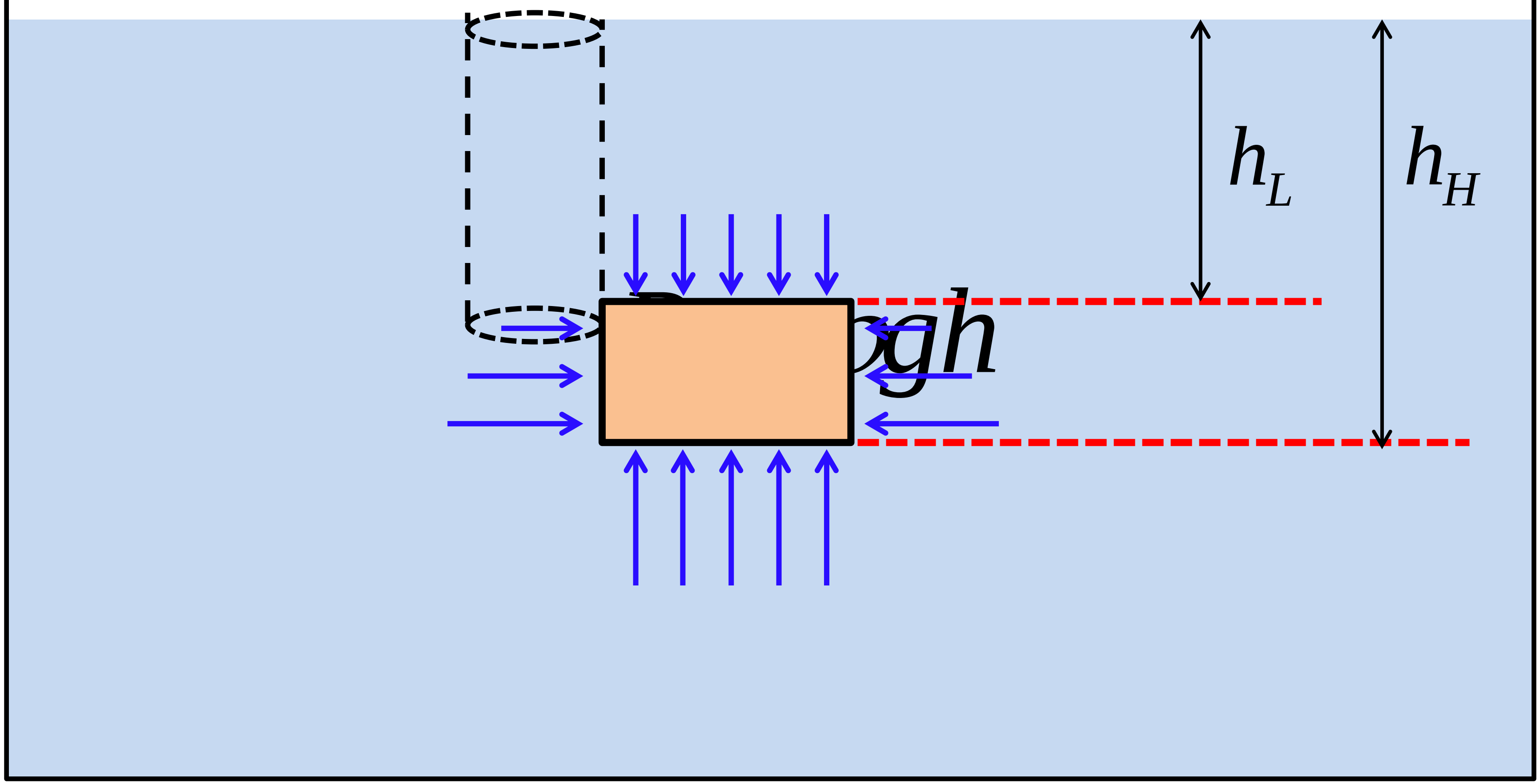
# Definition of Buoyant Force

$$F = F_H - F_L$$

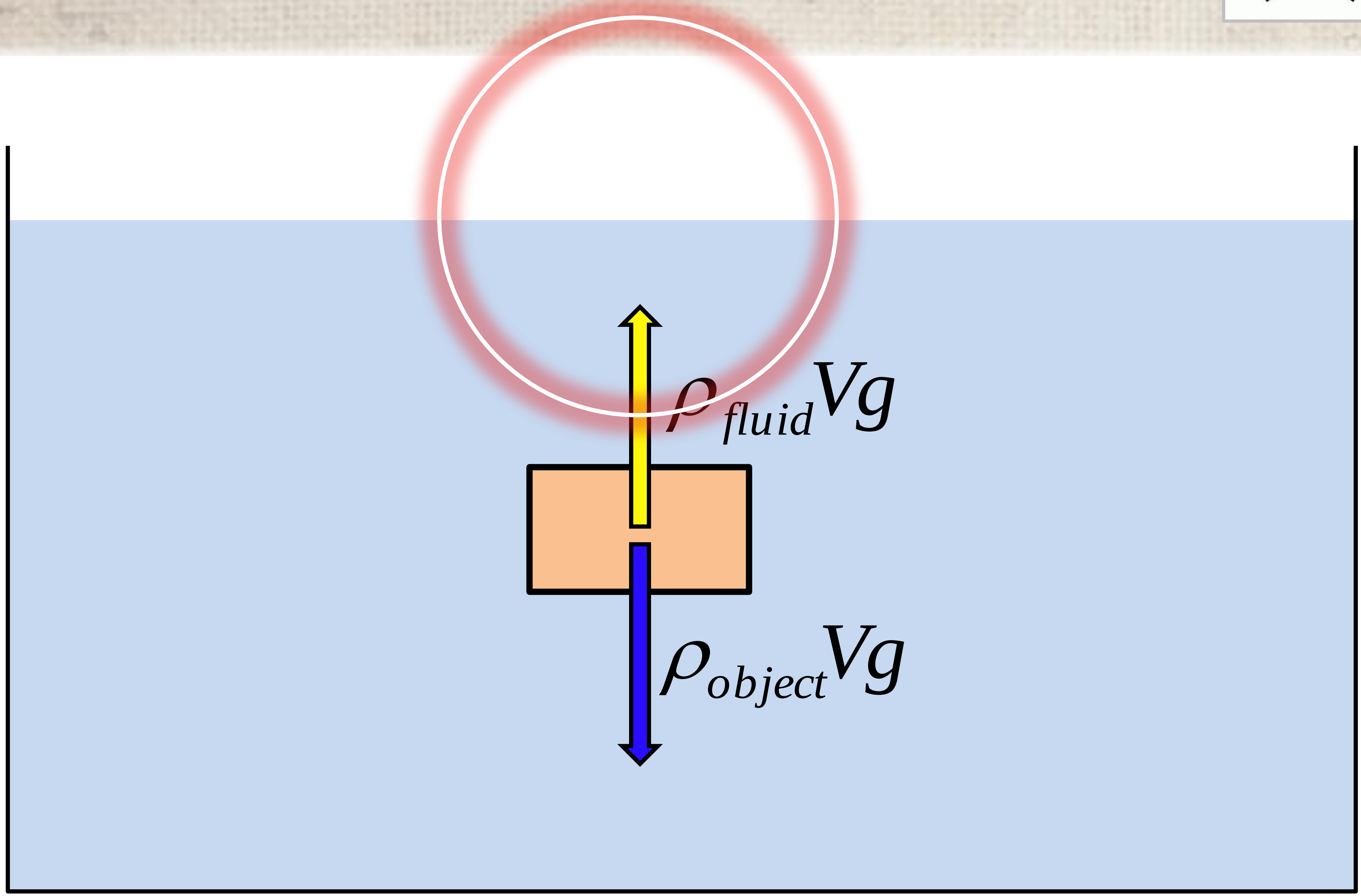
$$F = (P_H - P_L)A$$

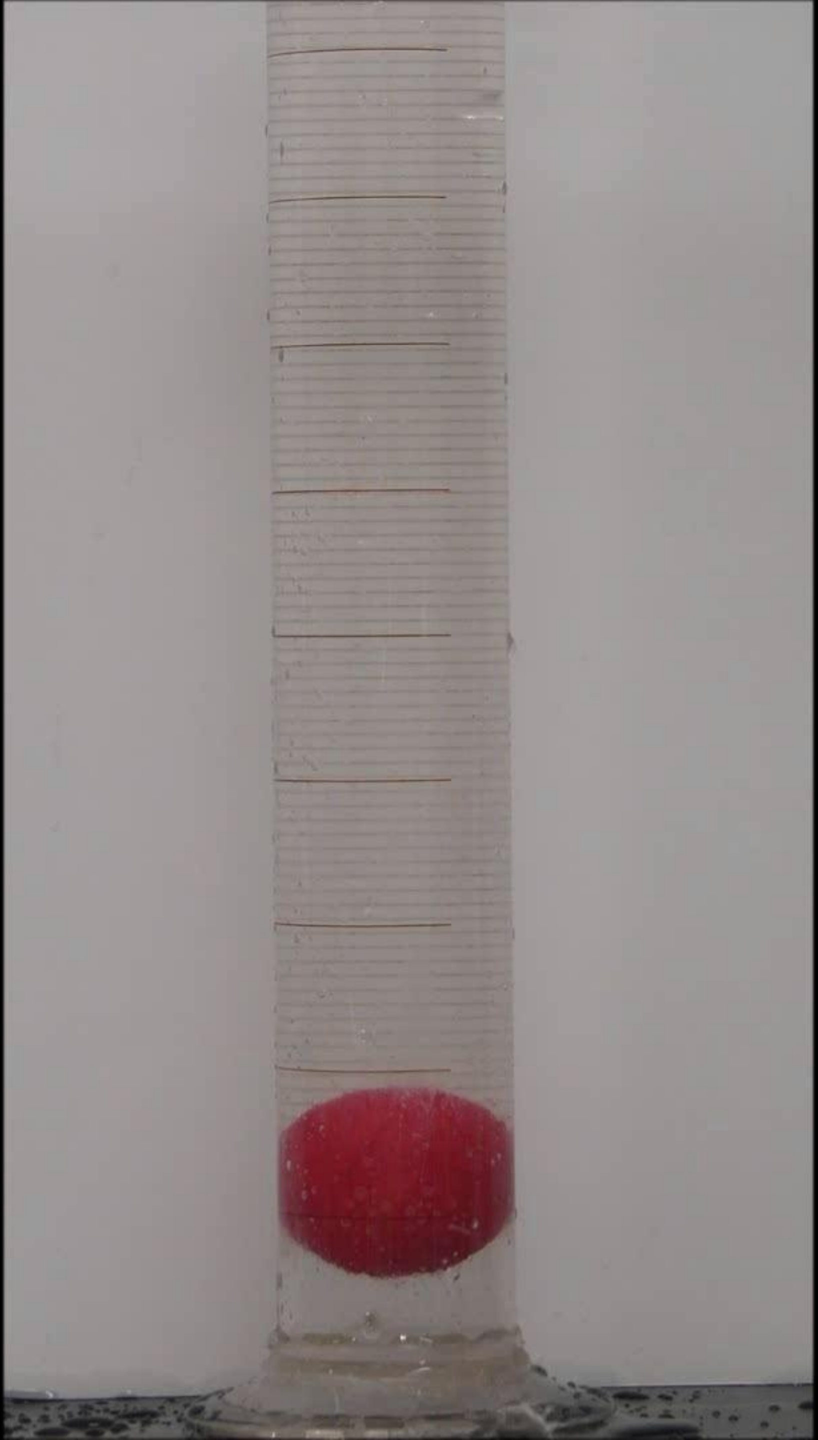
$$F = \rho g(h_H - h_L)A$$

$$F = \rho g V$$

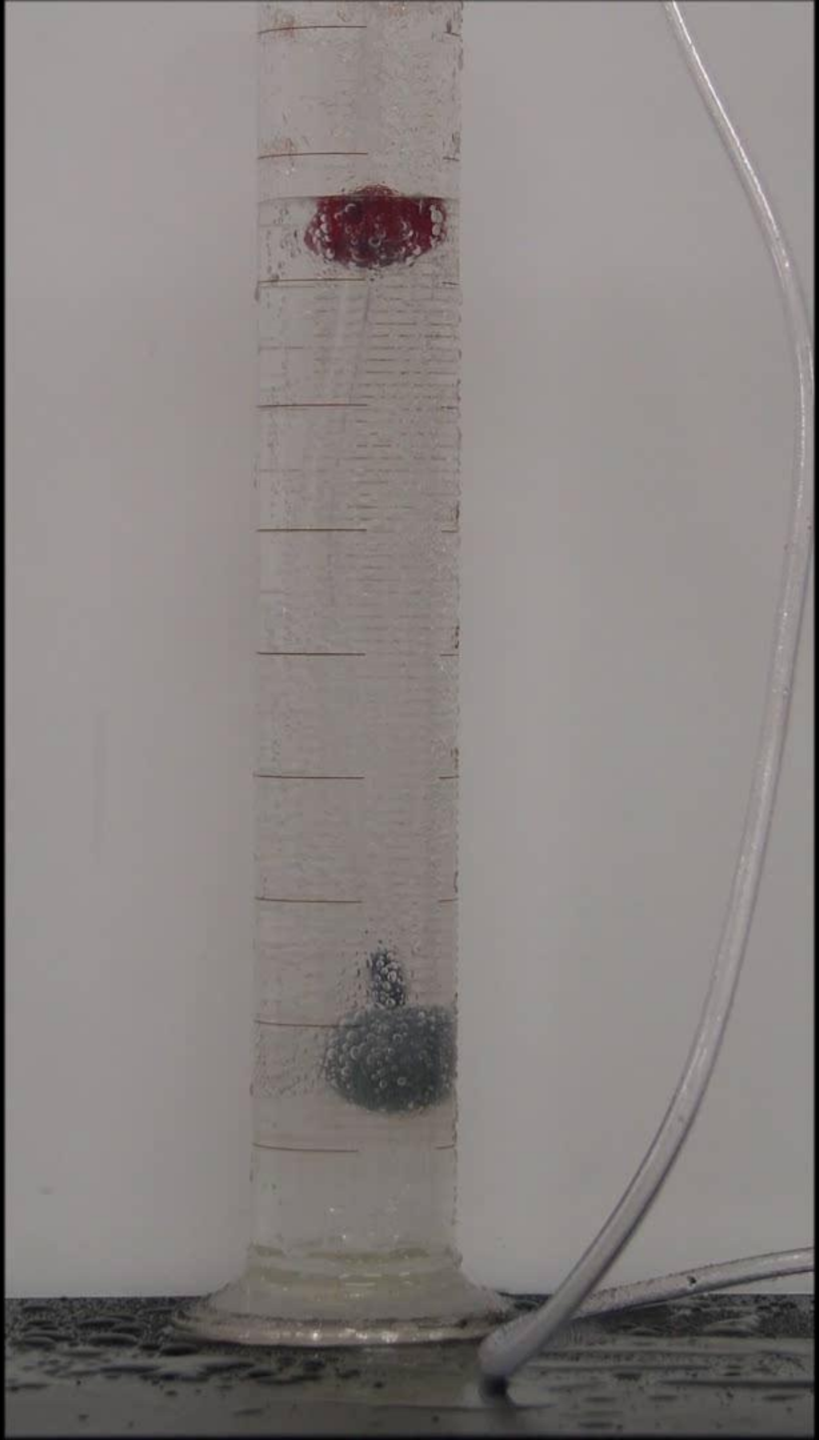


# Buoyant Force upon an Object

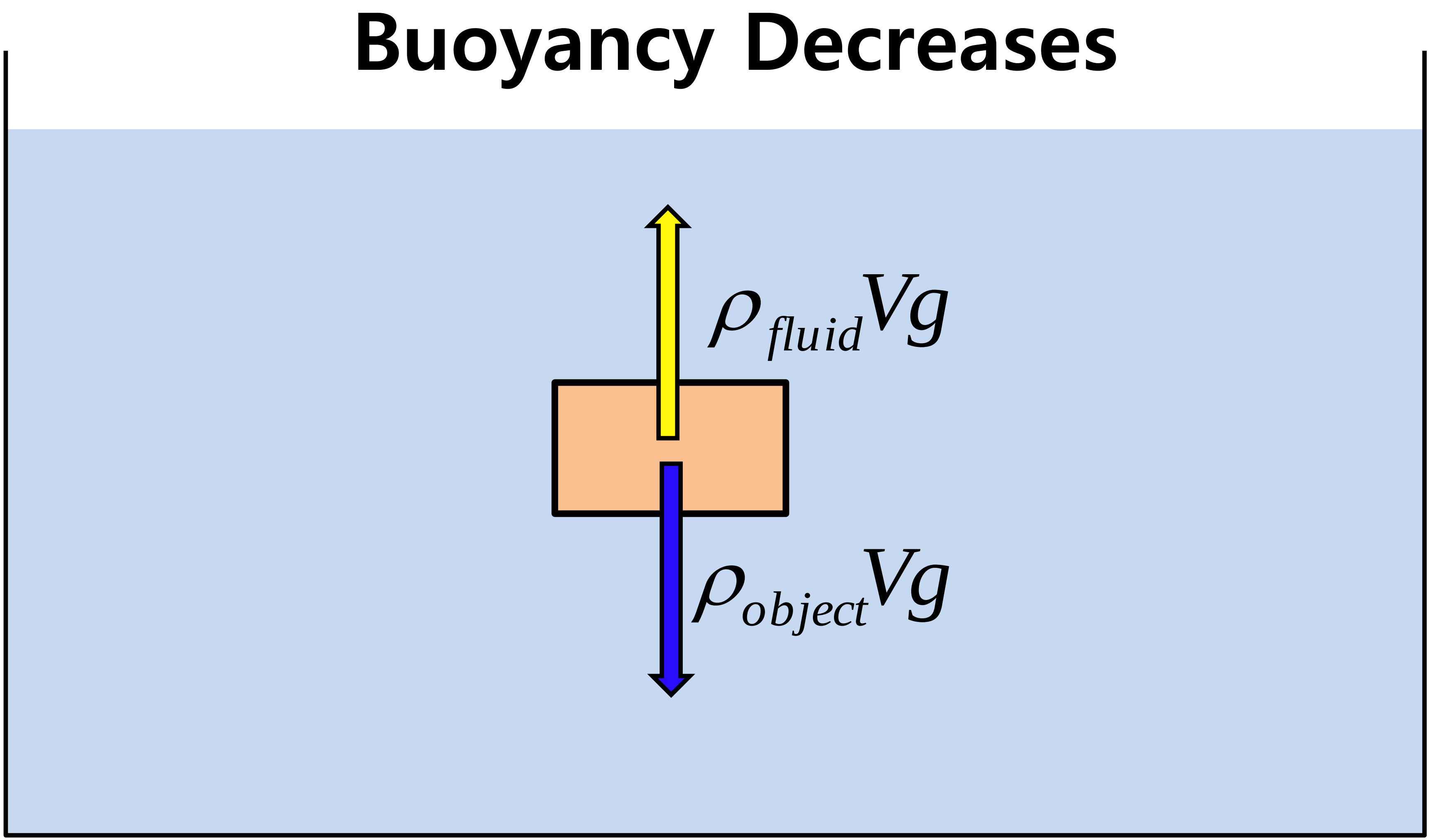




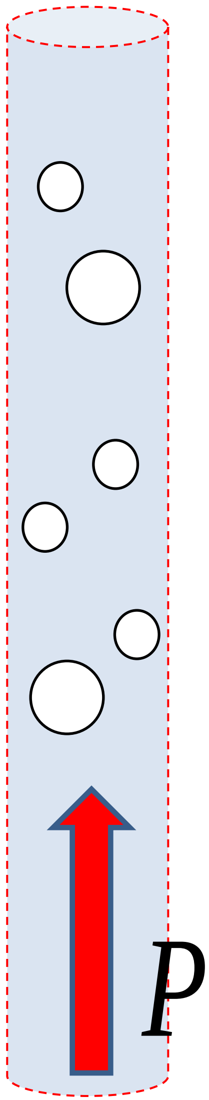
# Do Bubbles make a Difference?



# Force Diagram in case of Bubble Flow



# Static Bubbles – Buoyant Force



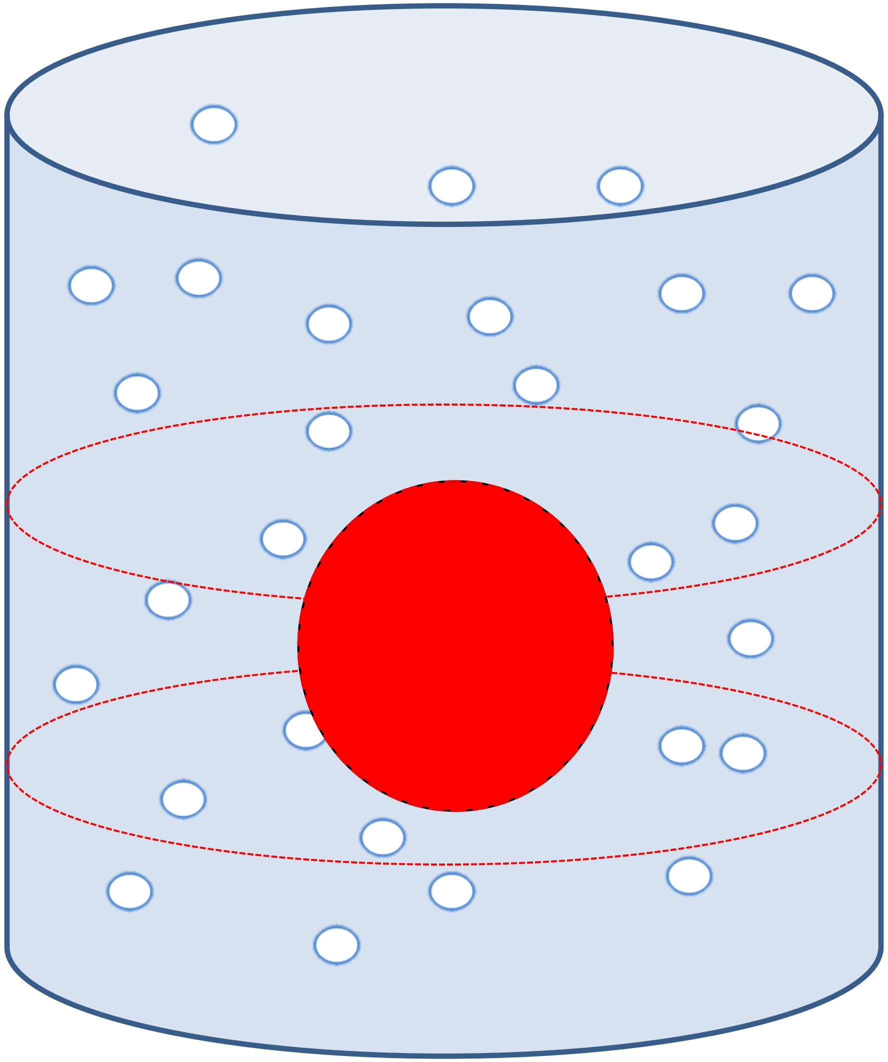

$$PA = (M_{water} + m_{bubble})g \approx M_{water}g$$

$$\frac{V_{water}}{V_{total}} = k$$ **(Water fraction)**

$$(\rho V_{total} k)g = (\rho k)gV_{total} = \rho' gV_{total}$$

$$\rho_{effective} \rightarrow \rho'$$

# Static Bubbles – Buoyant Force



Force upon object

$$F_B = \rho kgV$$

$$P_a = \rho kgh_a$$

$$P_b = \rho kgh_b$$

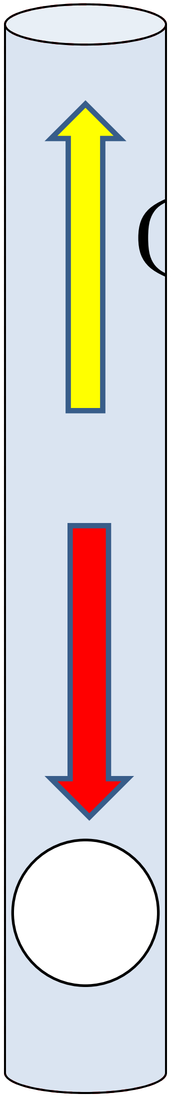
# Difference between

# Static Bubbles

# and

# Dynamic Bubbles

# Dynamic Bubbles – Motion of Bubble



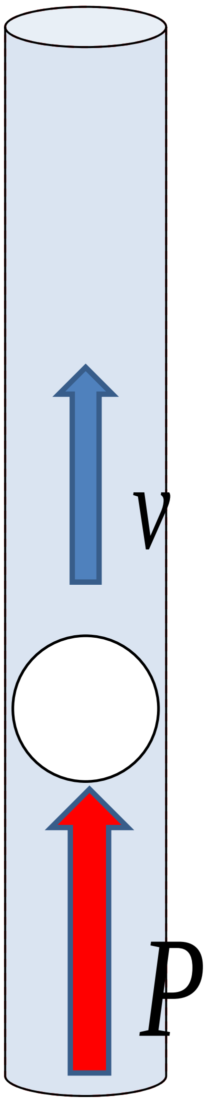
$$(\rho_{fluid} - \rho_{air})gV$$

**Drag Force = Velocity - Dependent**

$$c_1 v + c_2 v^2$$

**Terminal Velocity**

# Dynamic Bubbles – Buoyant Force




## Bubble at Terminal Velocity

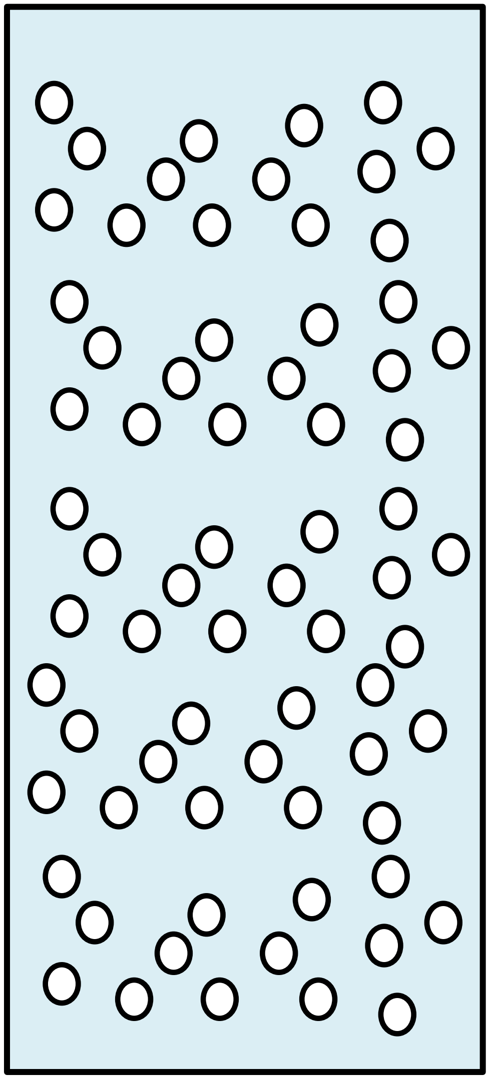
$$(M_{water} + m_{bubble})g - \Delta PA = (M + m)a_{c.o.m.}$$

$$a_{c.o.m.} = \frac{m\dot{v}}{M + m} = 0$$

$$\Delta PA = (M_{water} + m_{bubble})g \approx M_{water}g$$

$$M_{water}g = M_{water}'g\frac{V_{water}}{V_{whole}} = M_{water}'gk$$

# Multi-Bubble System



***Input of Bubbles = Output of Bubbles***

***Bubbles at constant Velocity***

***Center of Mass DOES NOT CHANGE!***

**Same Condition…How?**

# Use of Viscous Liquid

## Laminar Flow in Silicon Oil

**Kinematic Viscosity = 0.89m^2/s**

$$Re = \frac{Lv}{\mu}$$

**L=pipe diameter**

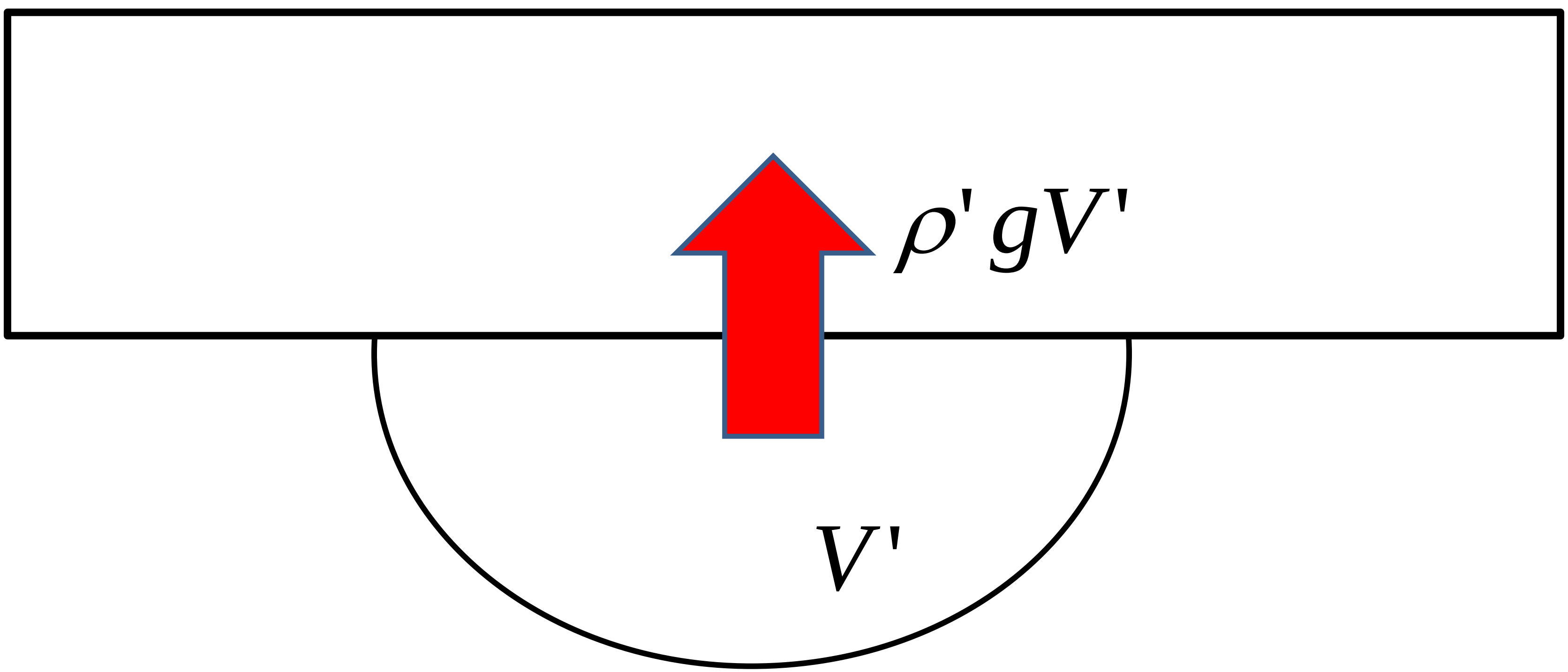
**$\mu$=kinematic viscosity**

$$Re = 0.92v(cm/s)$$

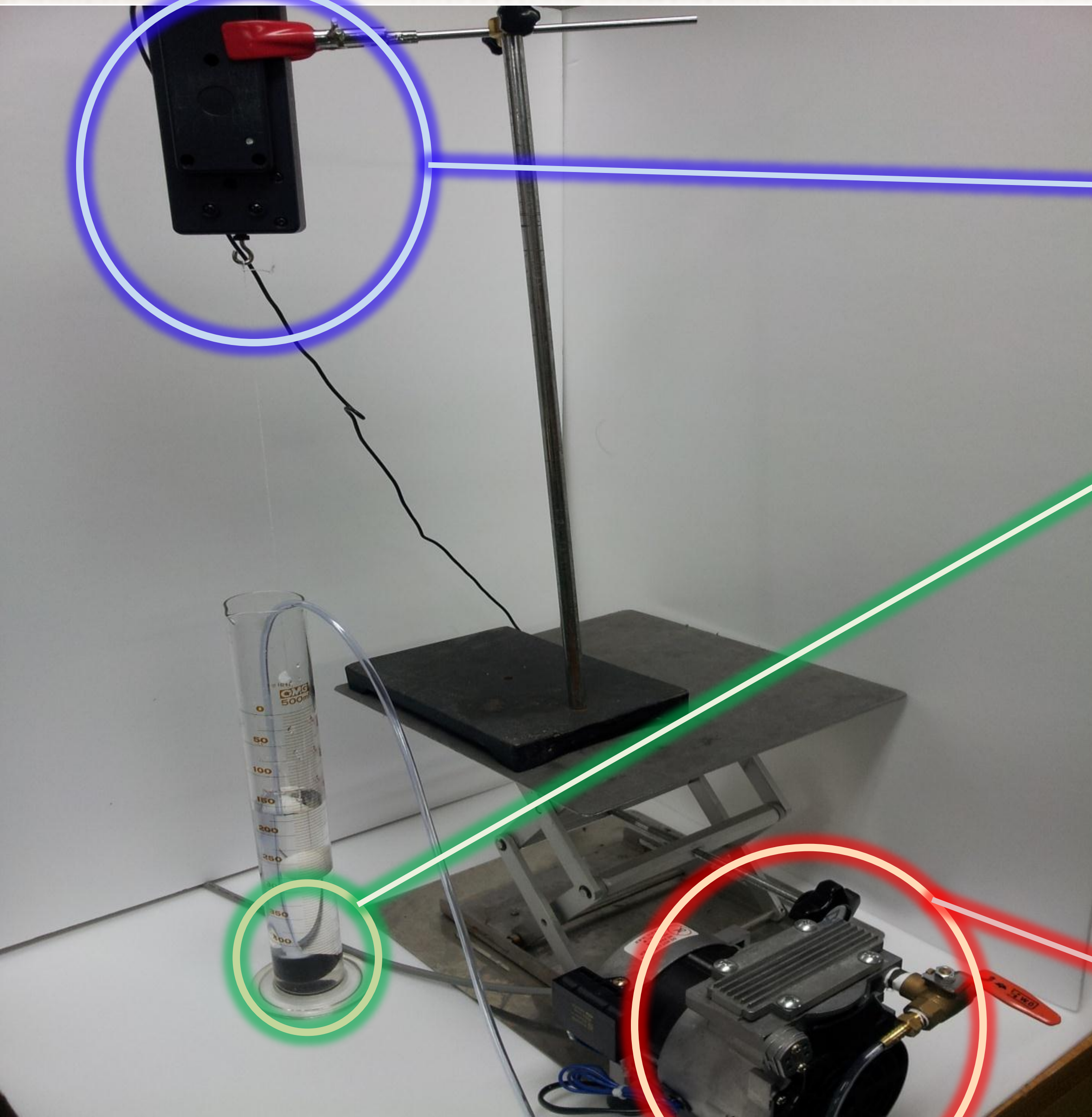
$$Re < 10$$

**Laminar Flow, Constant Velocity**

# Buoyant Force by Bubbles




# Experiment Setting

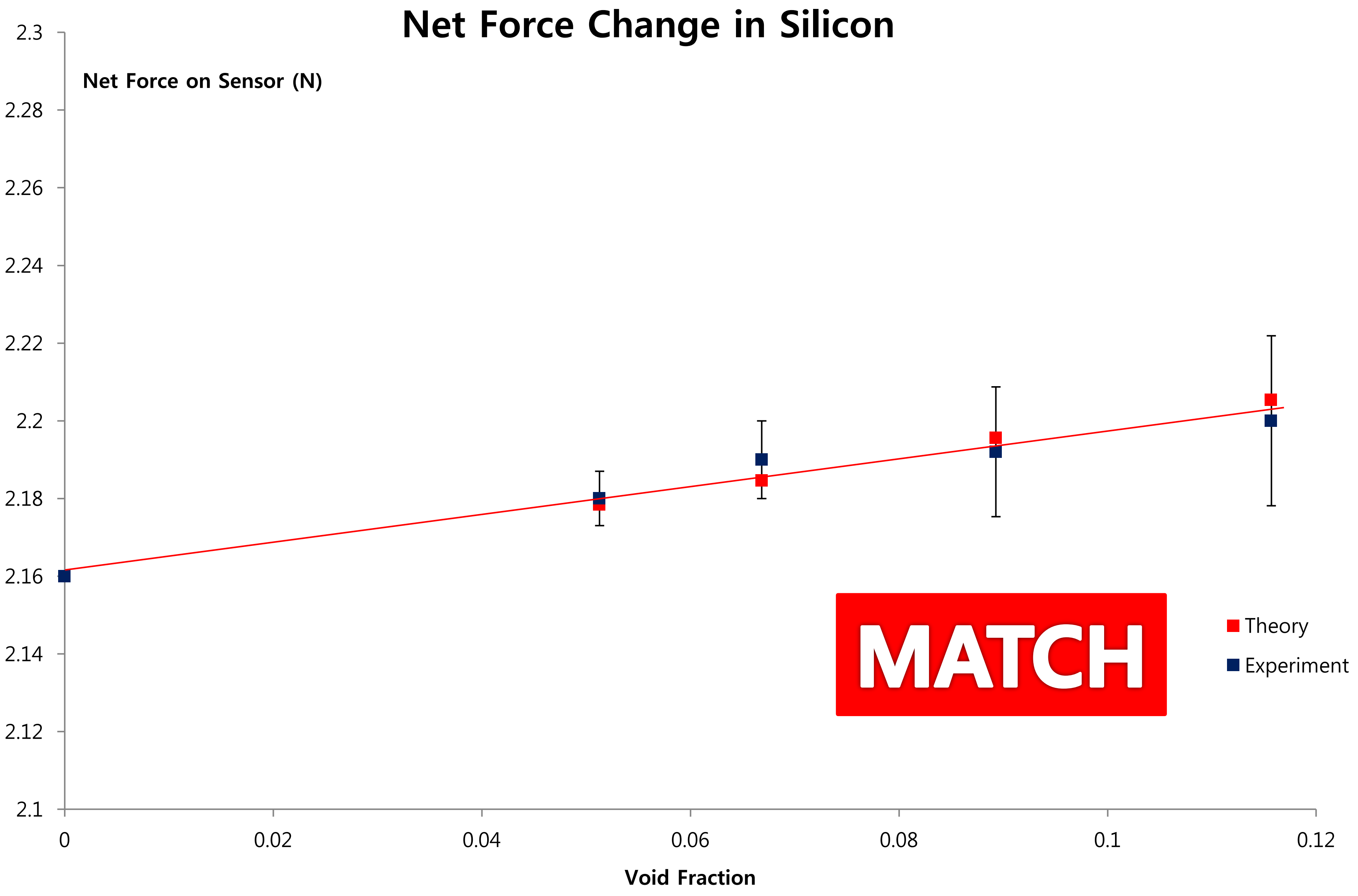


**Force Sensor**

**Bubble Diffuser**

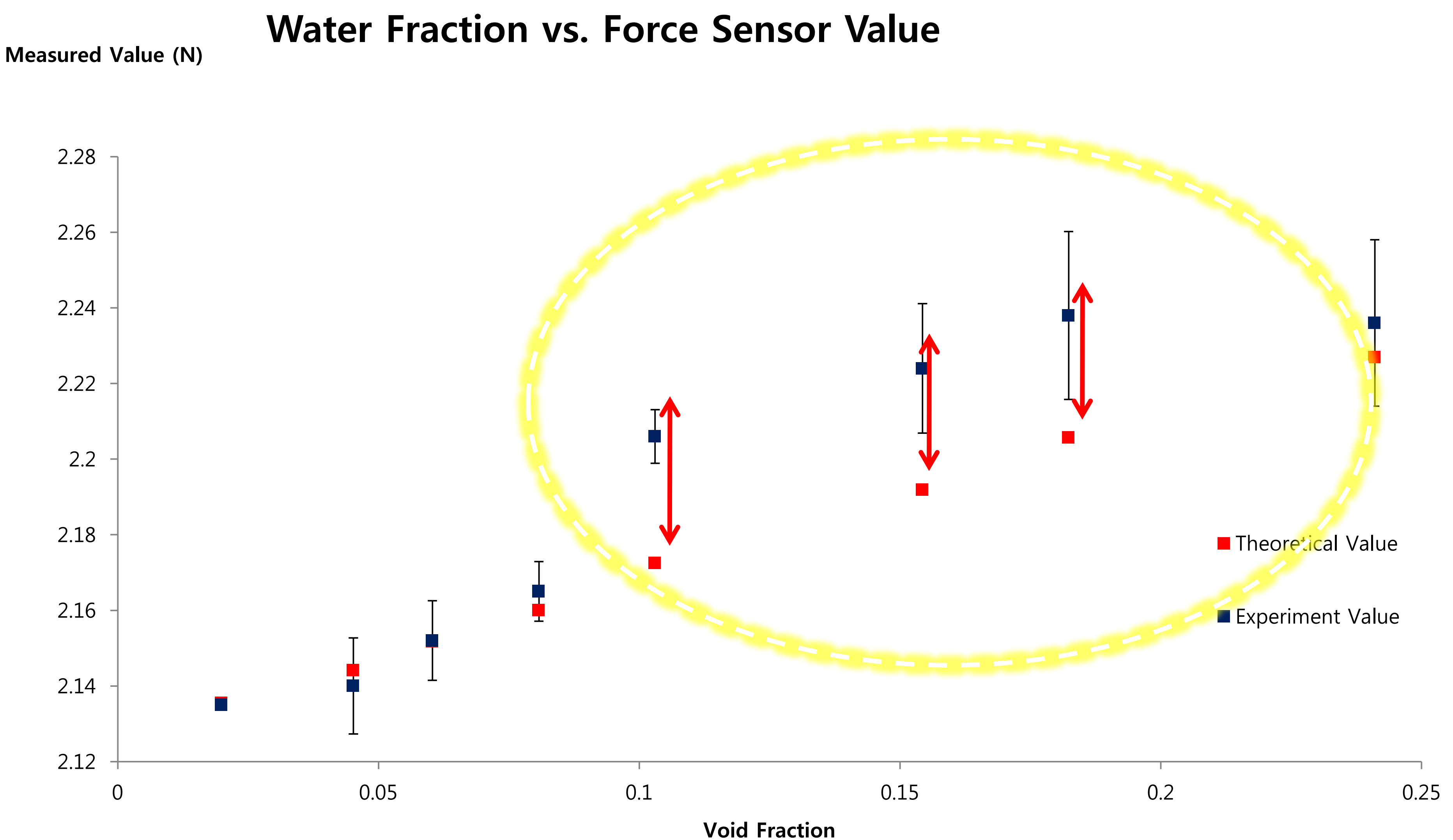
**Air Pump**

# Theory vs. Experiment

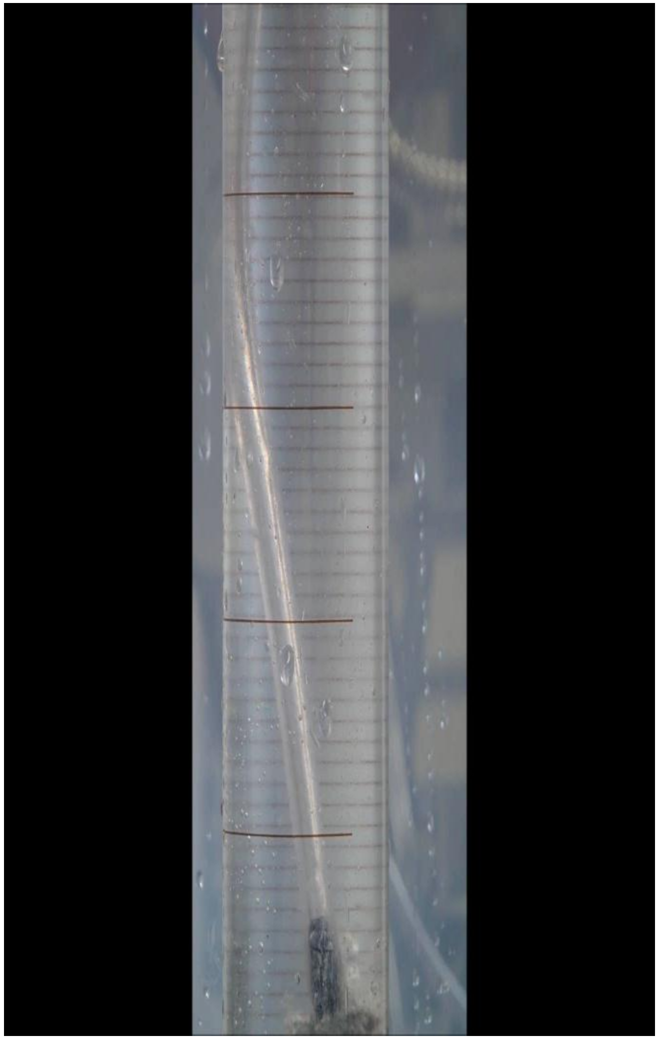


# How about Water ?

# Theory vs. Experiment



# Dynamic Turbulence in Water



## Turbulence in Water

**Kinematic Viscosity = 1.004*10^-6(m^2/s)**

$$\mathrm{Re} = \frac{Lv}{\mu}$$

**L=pipe diameter**

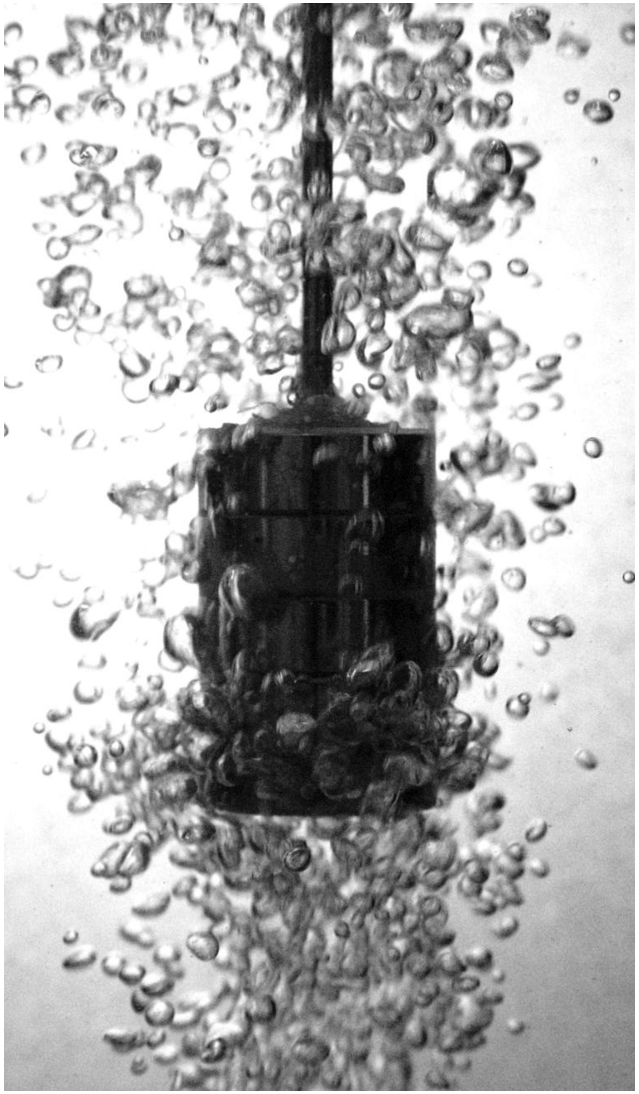
**$\mu$=kinematic viscosity**

$$\mathrm{Re} = 458.16v(cm/s)$$

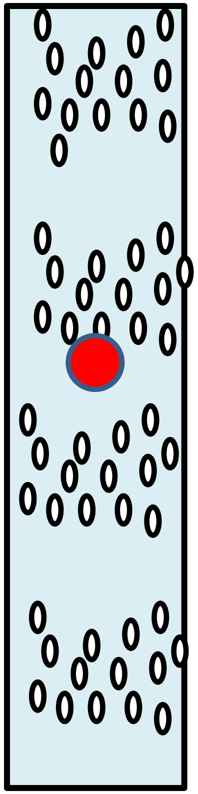
$$\mathrm{Re} > 2000$$

**Very Turbulent**

# Turbulence?



Air Flow in Water



***Center of Mass FLUCTUATES!***

***Non-uniform Bubble Velocity***

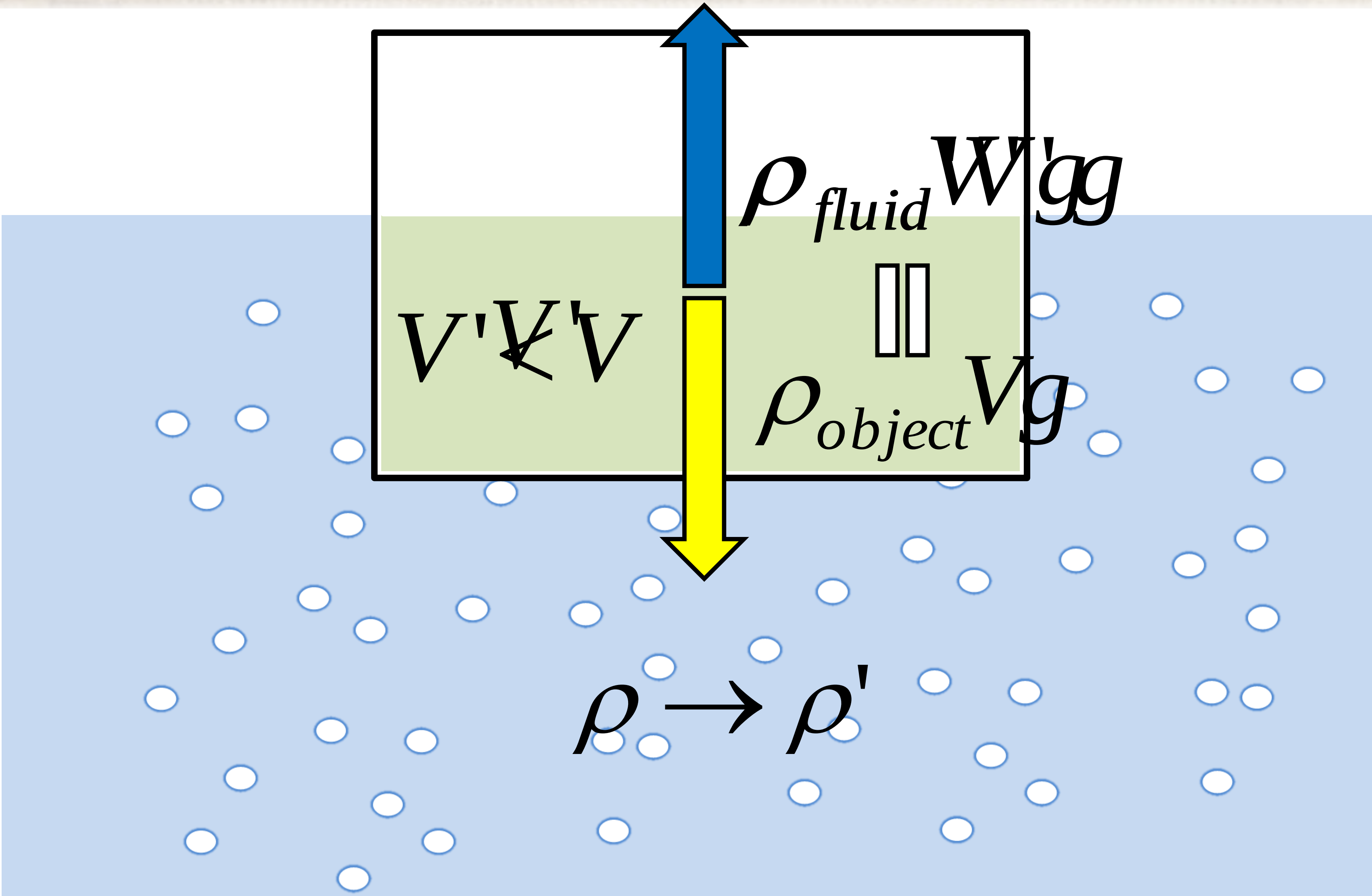
***-High STD of Force***

***Turbulent Drag – FORCE!***

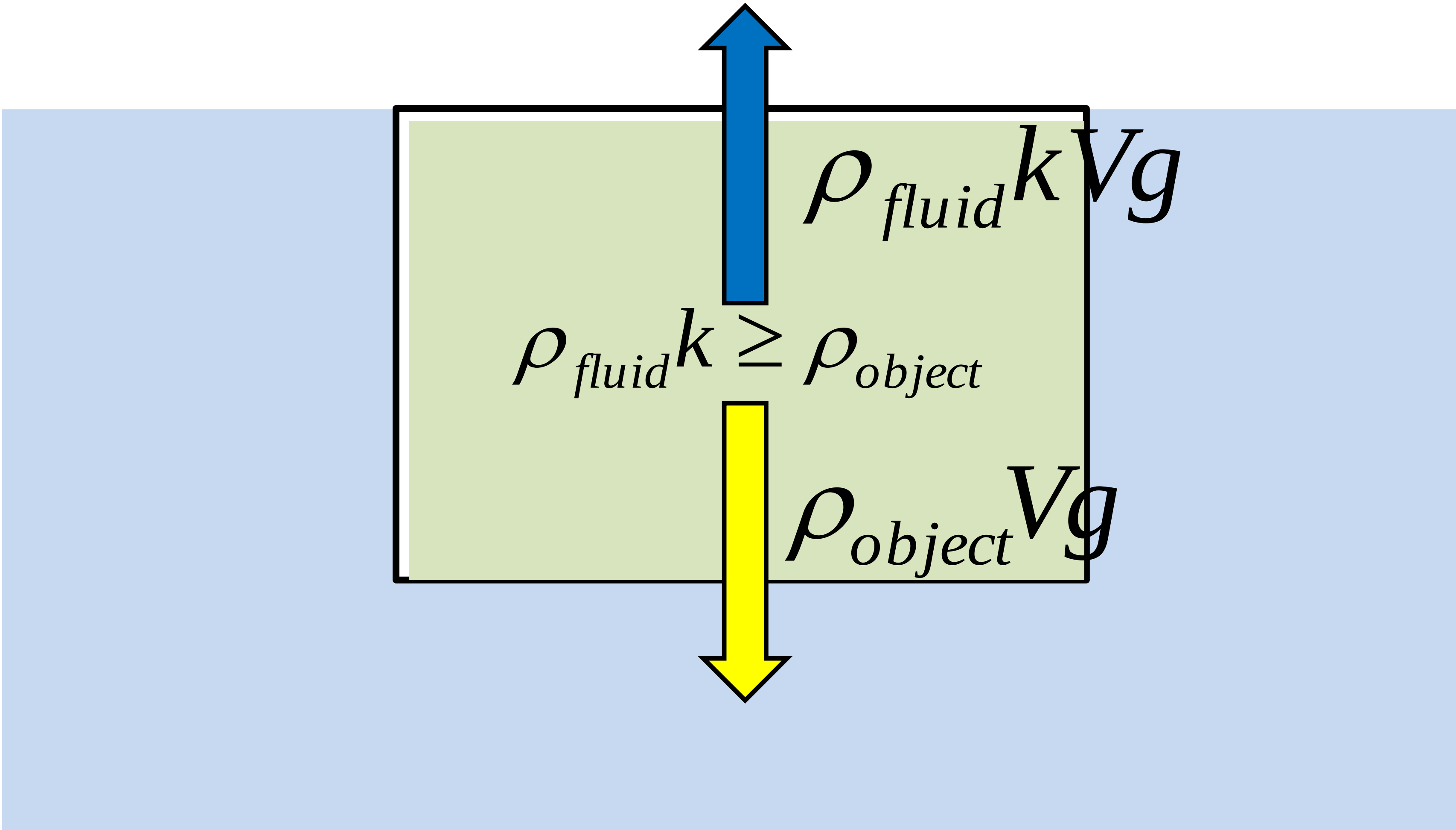
***-Additional Factor***

# Is it Possible to FLOAT?

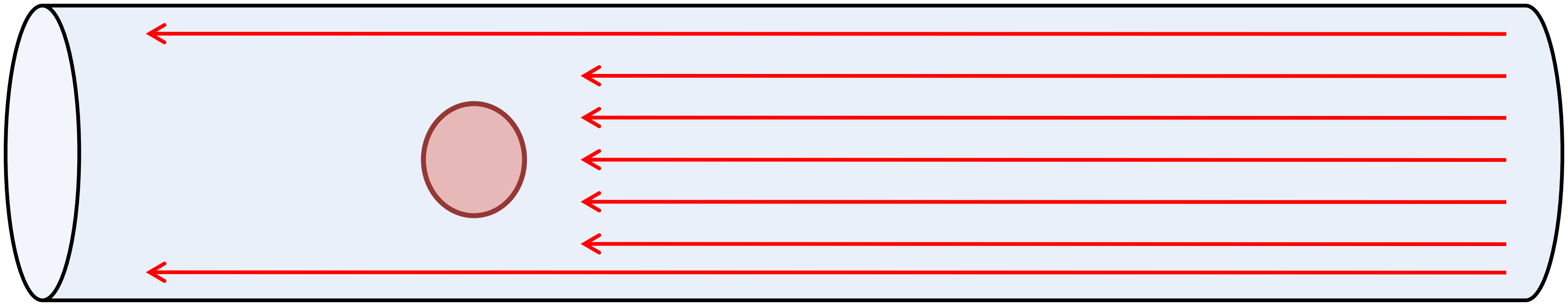
# Floating Condition without Drag



# Floating Condition



# The Effect of Drag Force



**Direction of Force** — Direction of Flow

**Magnitude of Force** — Velocity Dependent!

# Larger Scale Setting

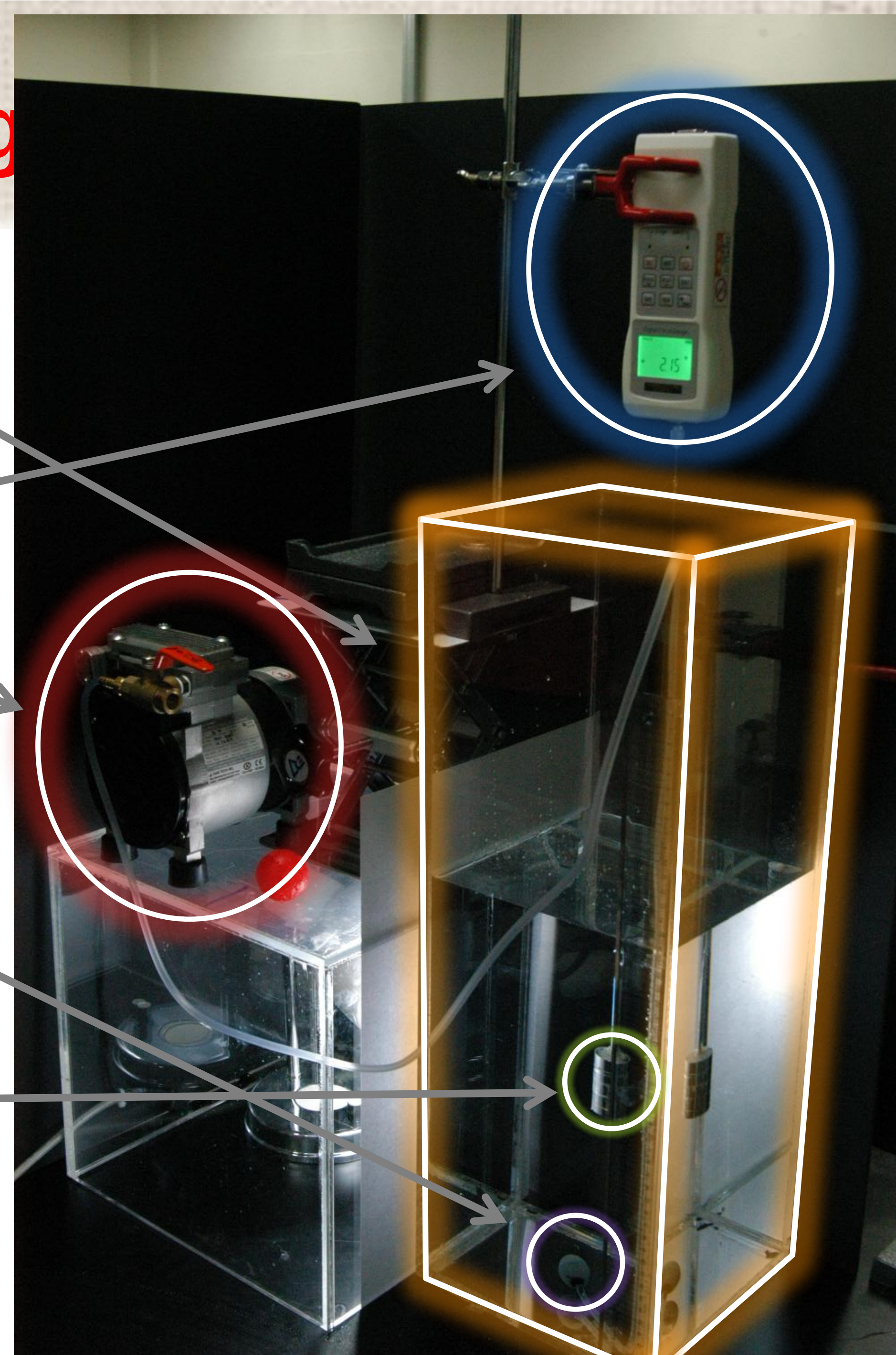
Water Tank

Force Meter

Air Pump

Bubble Diffuser

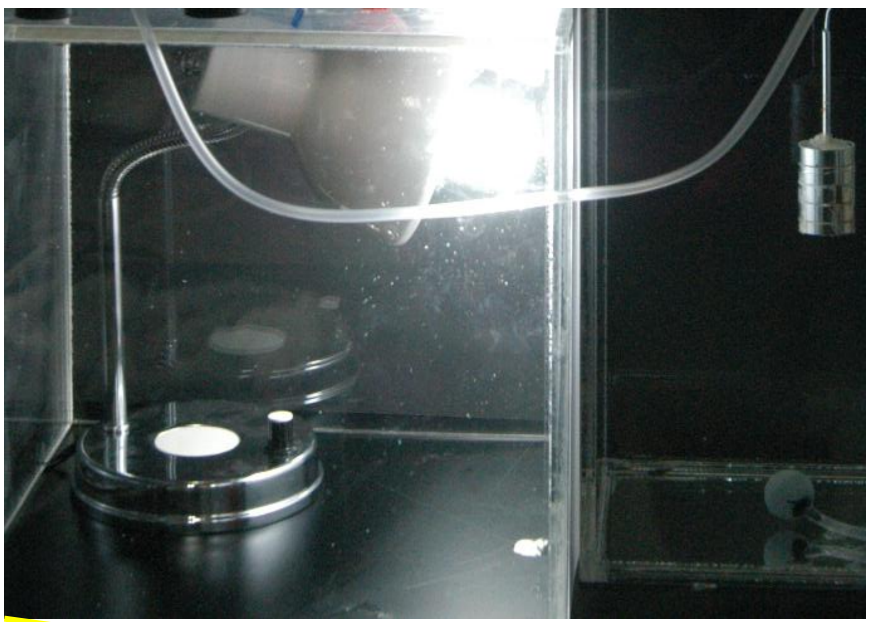
Weight

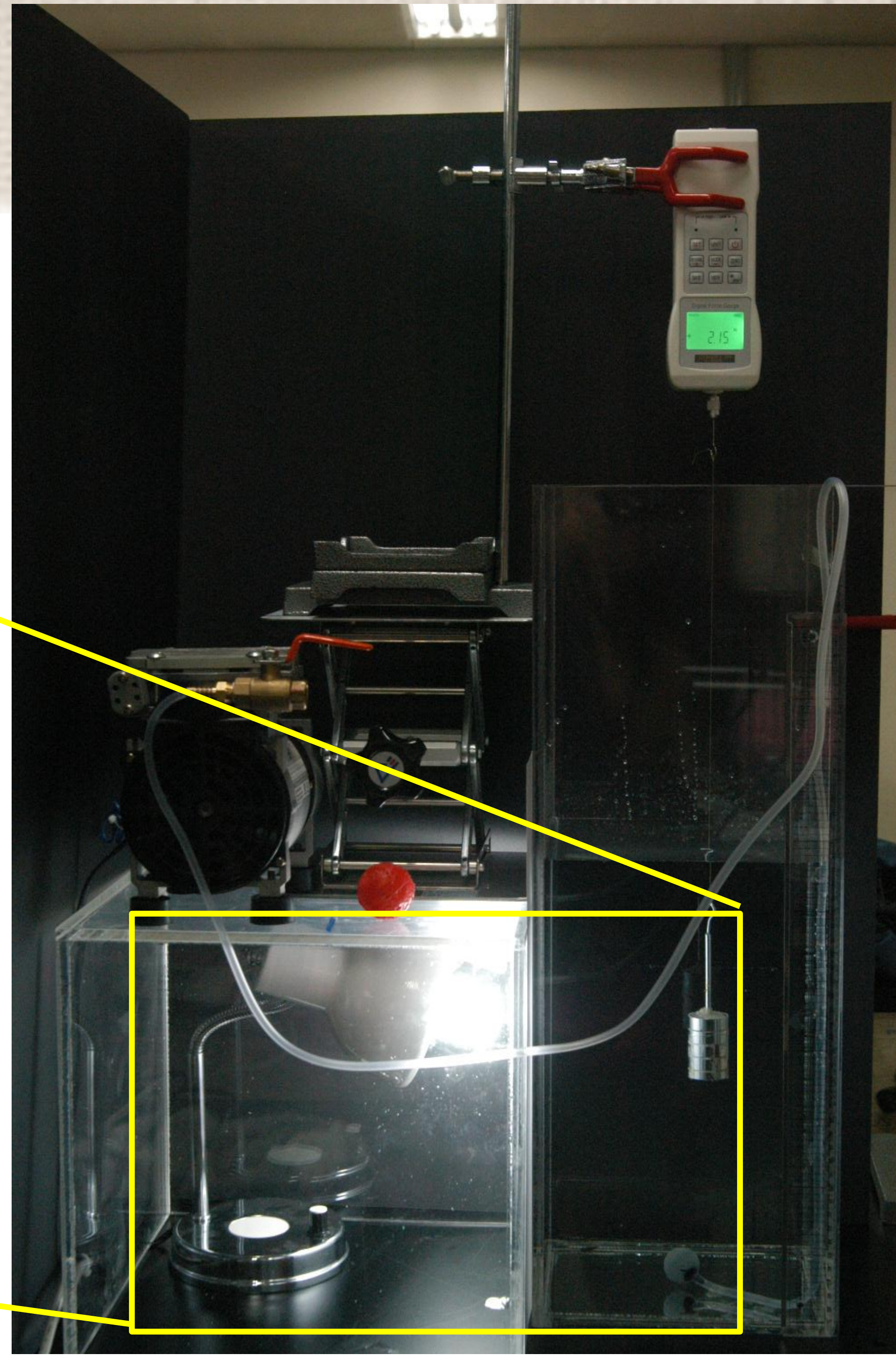


# Setting

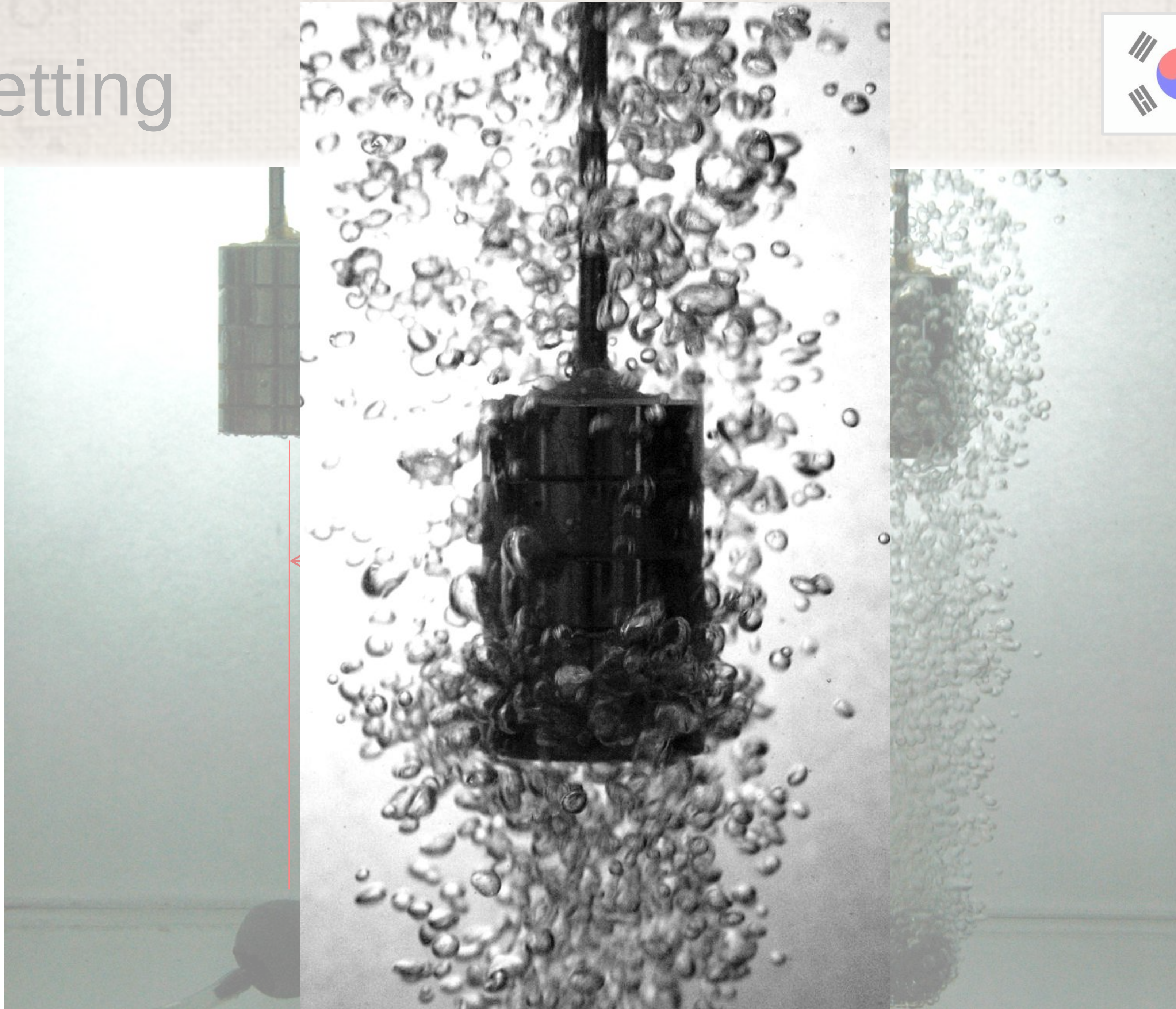
## **Light Source**

*Clearer Recognition of Bubbles*

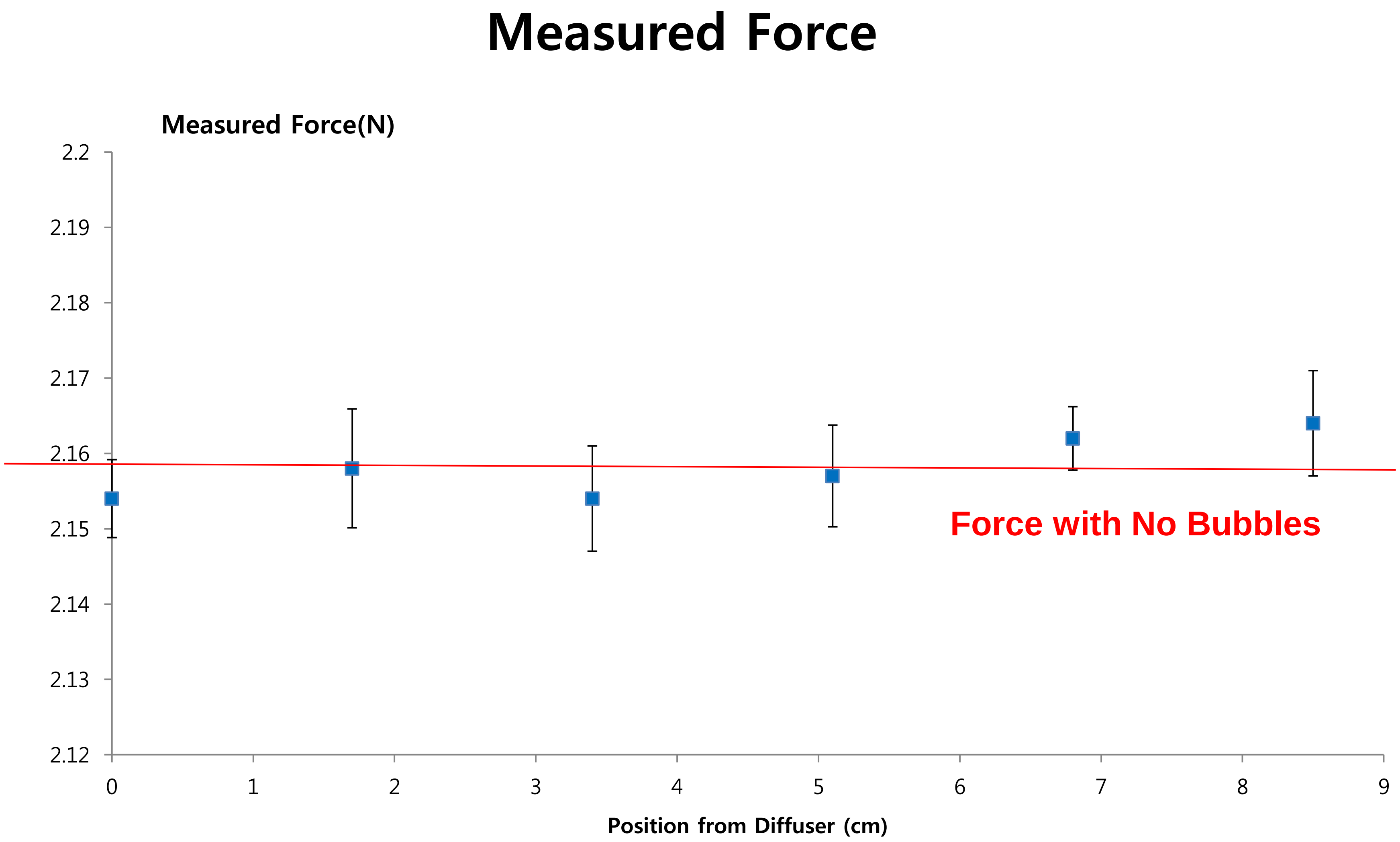




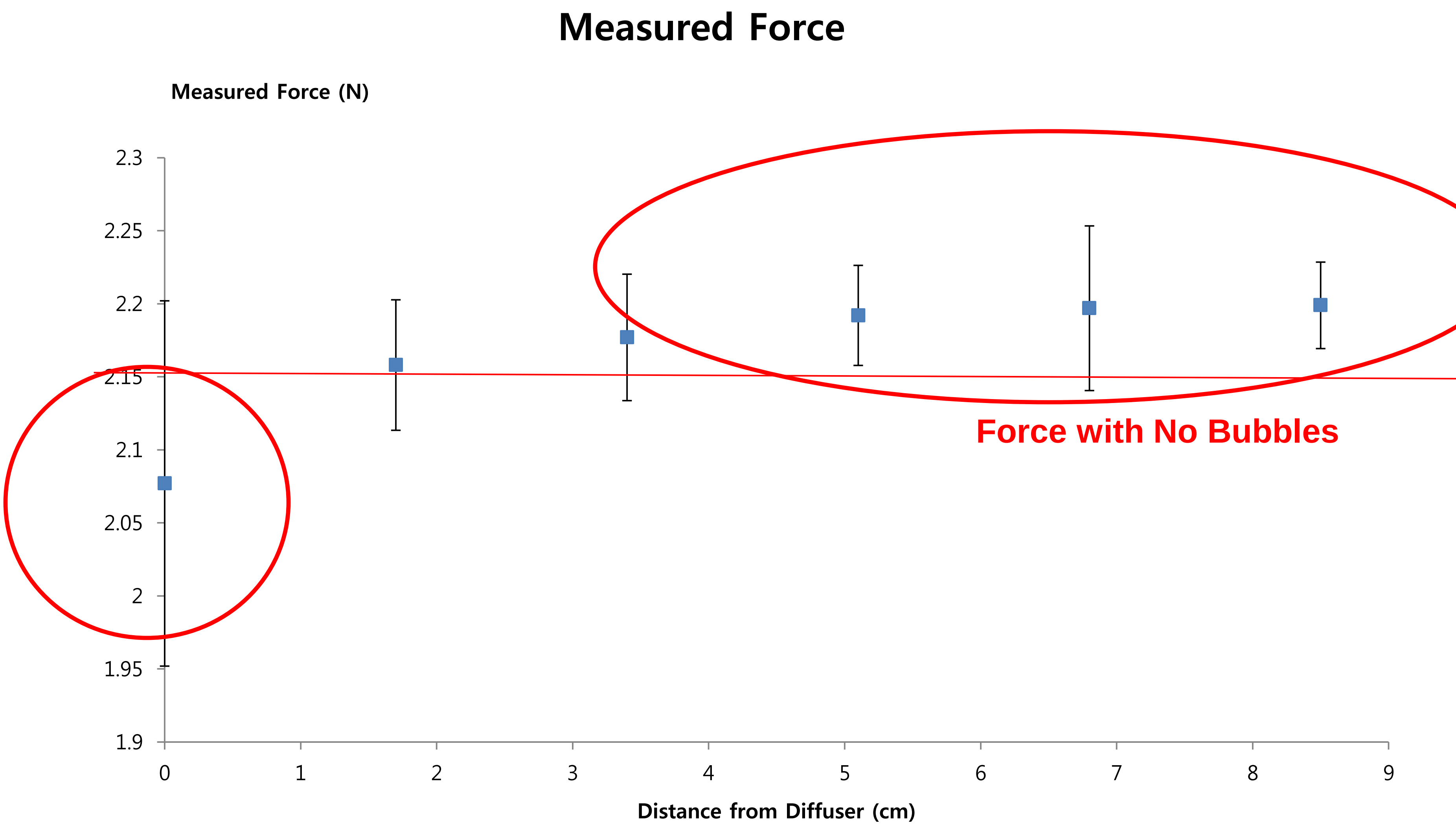
# Setting



# Low Flow Rate – Constant Force

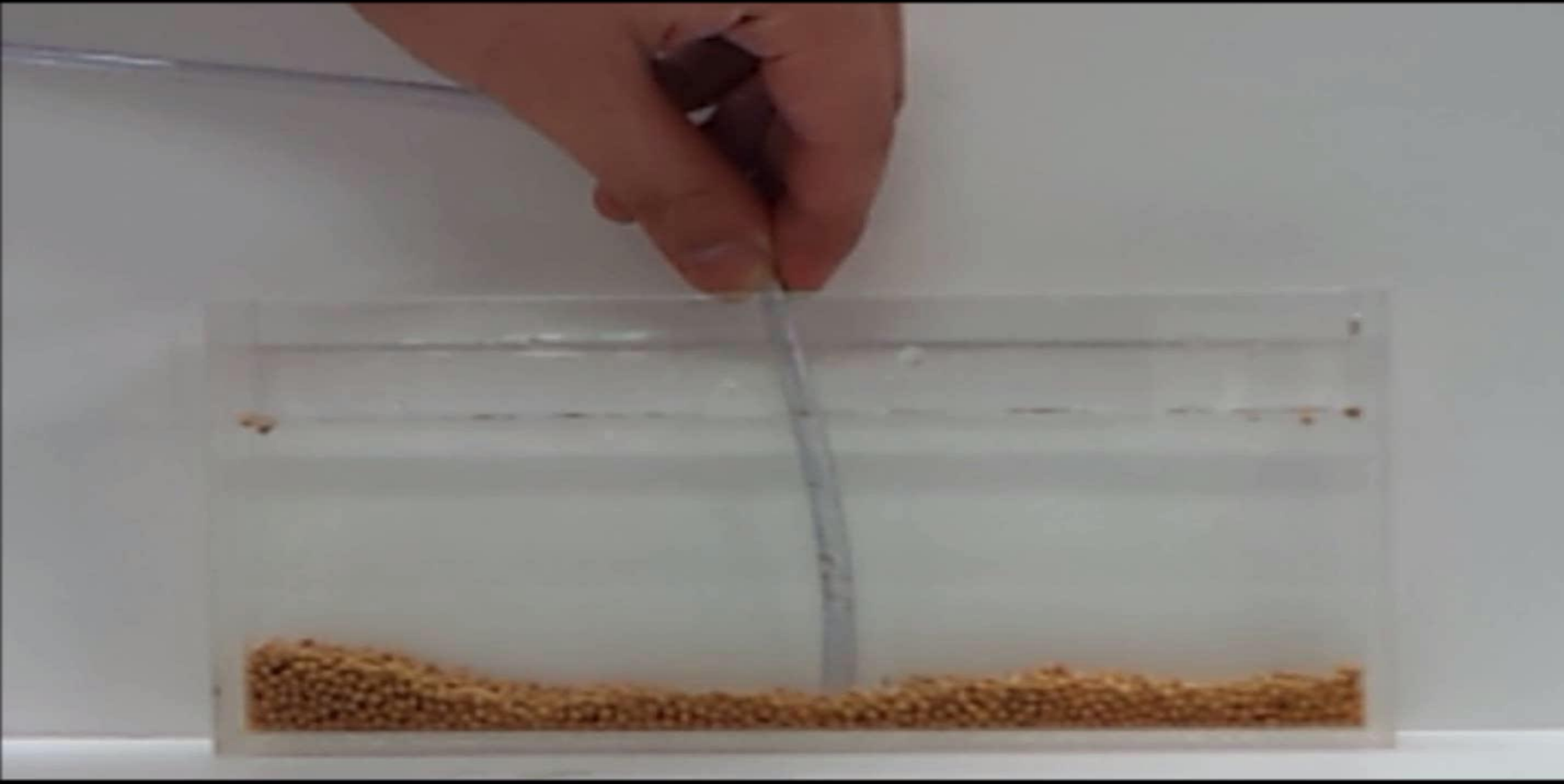


# High Flow Rate – Effect of Turbulence

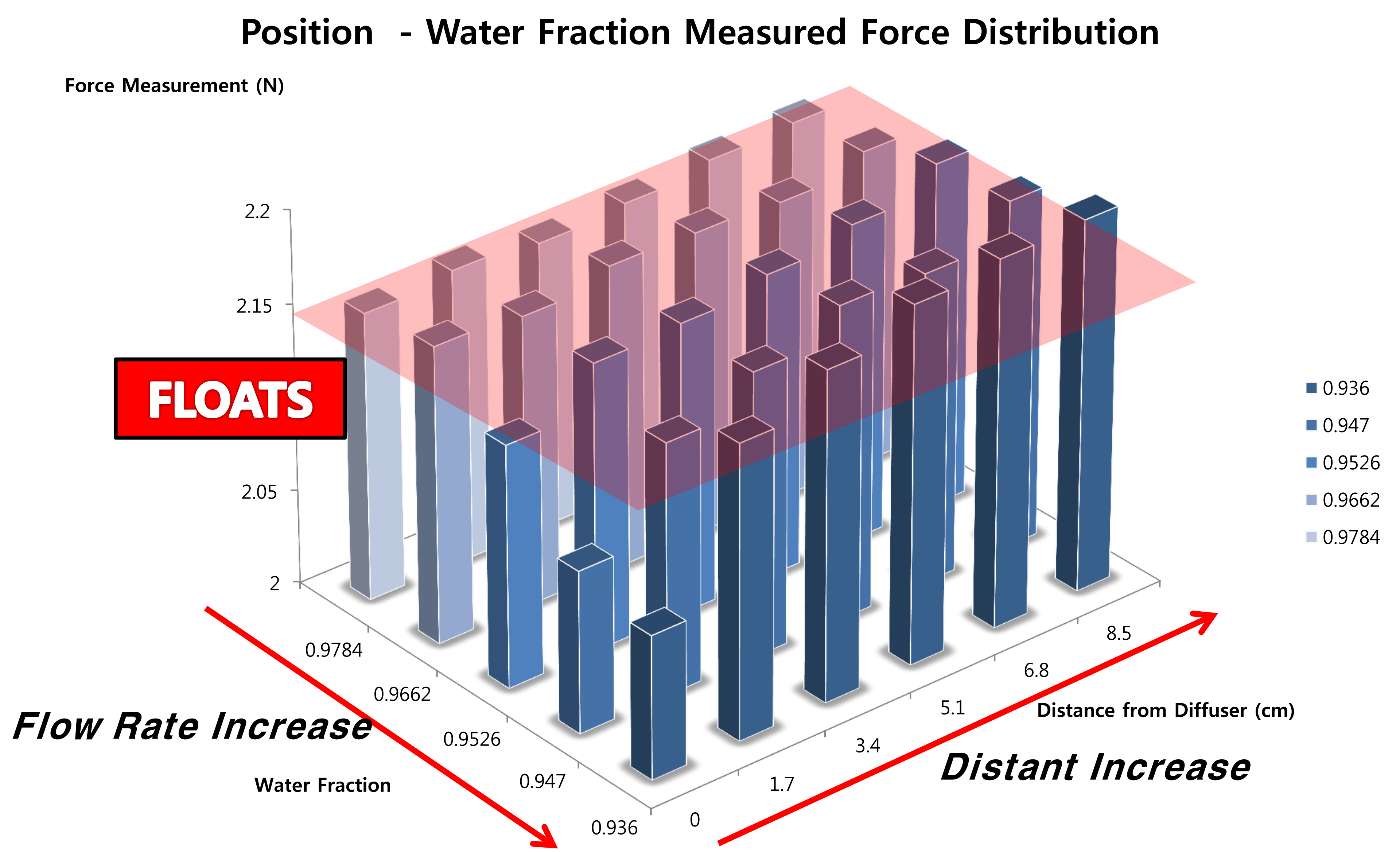


# Turbulence? Qualitative Explanation

**Force upon the object affected by FLOW**

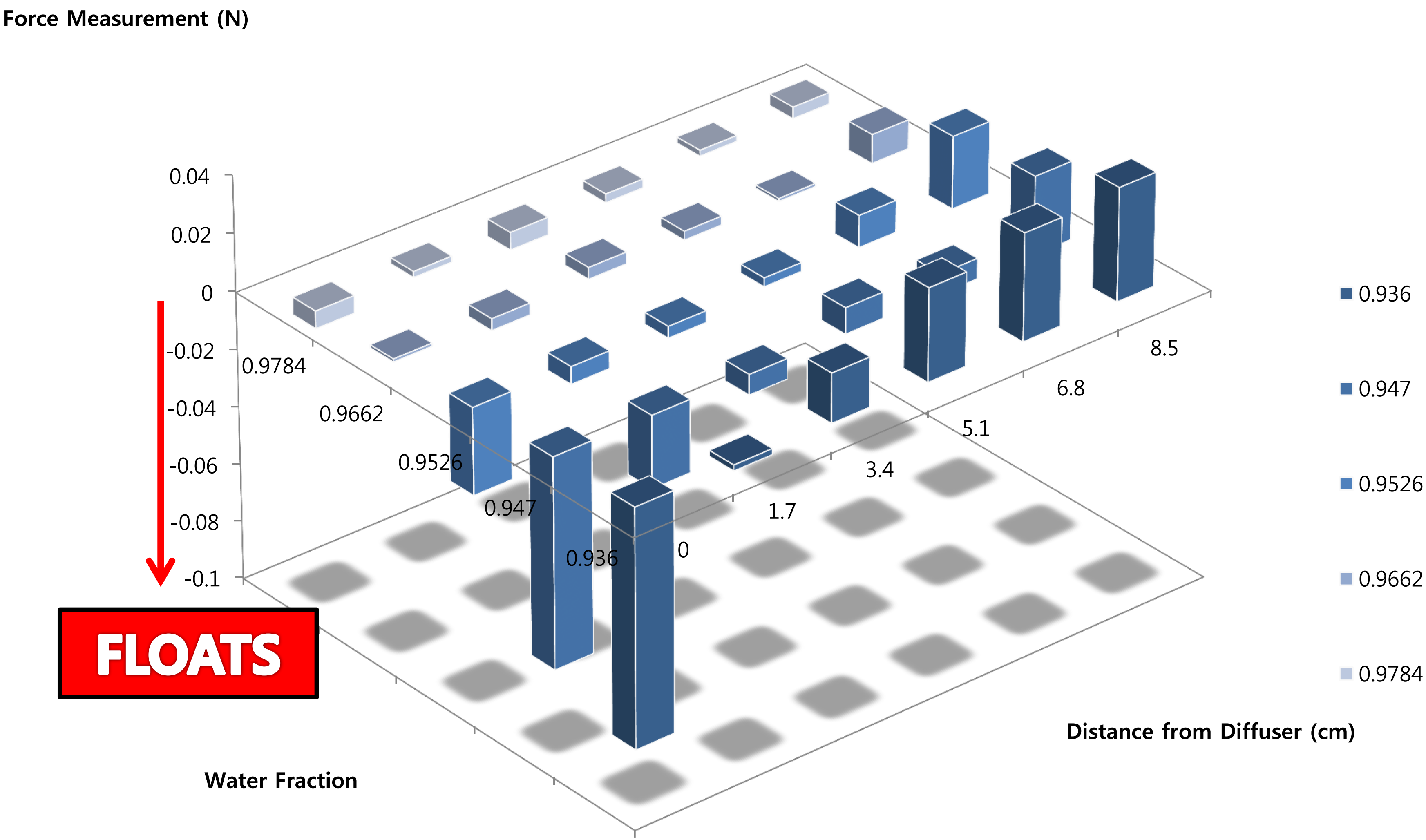


# Position-Water Fraction Force



# Position-Water Fraction Force

## Position - Water Fraction Measured Force Distribution



# Conclusion

## 1. Buoyancy and Bubbles?

**Model**

$$F_B = \rho k g V, k = \frac{V_{water}}{V_{total}}$$

**Confirmed with SILICON**

**Confirmed in water for Low Flow**

## 2. Is it possible to float?

**Density Condition**

$$\rho_{fluid} k \geq \rho_{object}$$

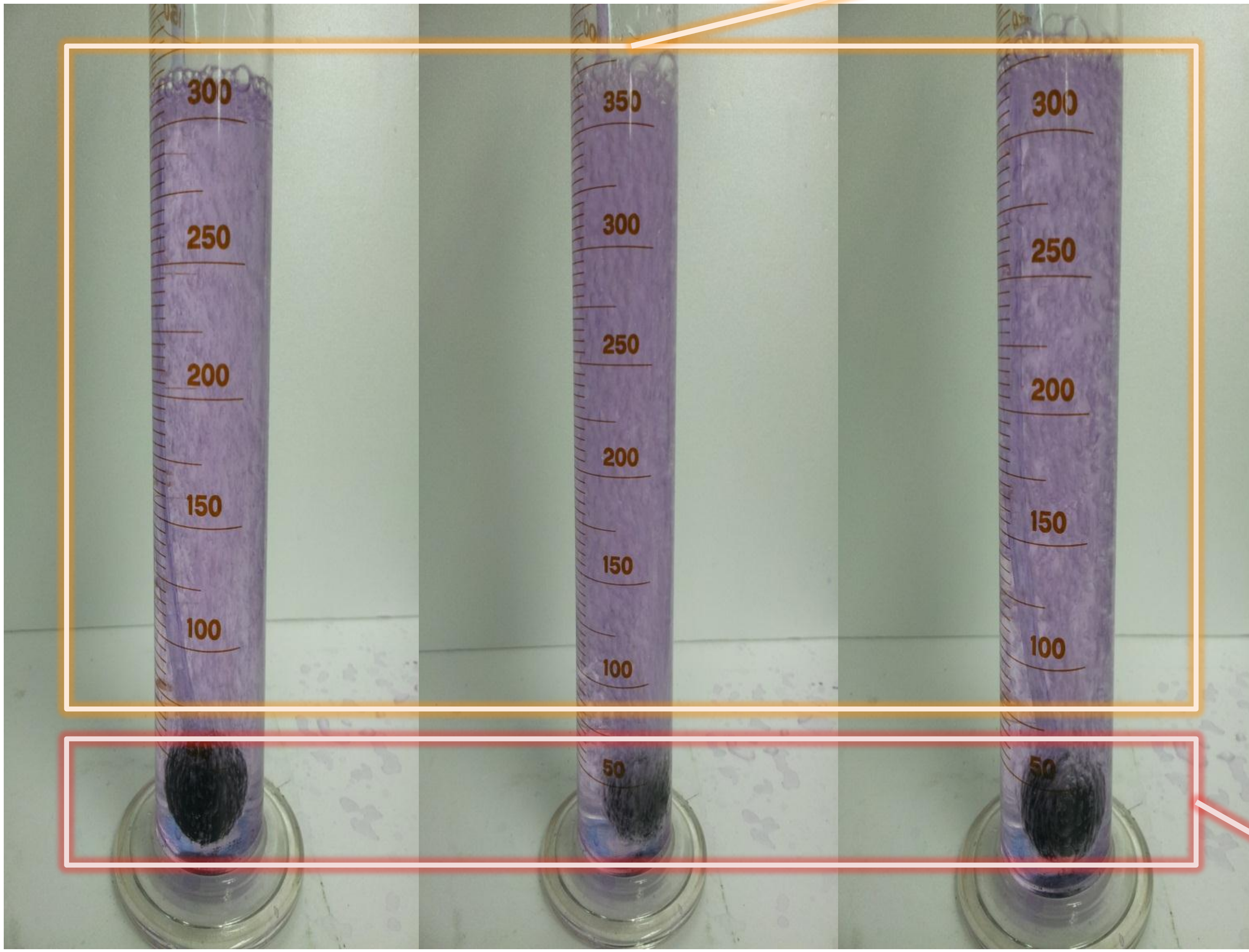
**Convection Force**

**Force by Flow**

# THANK YOU

# Uneven Distribution of Bubbles

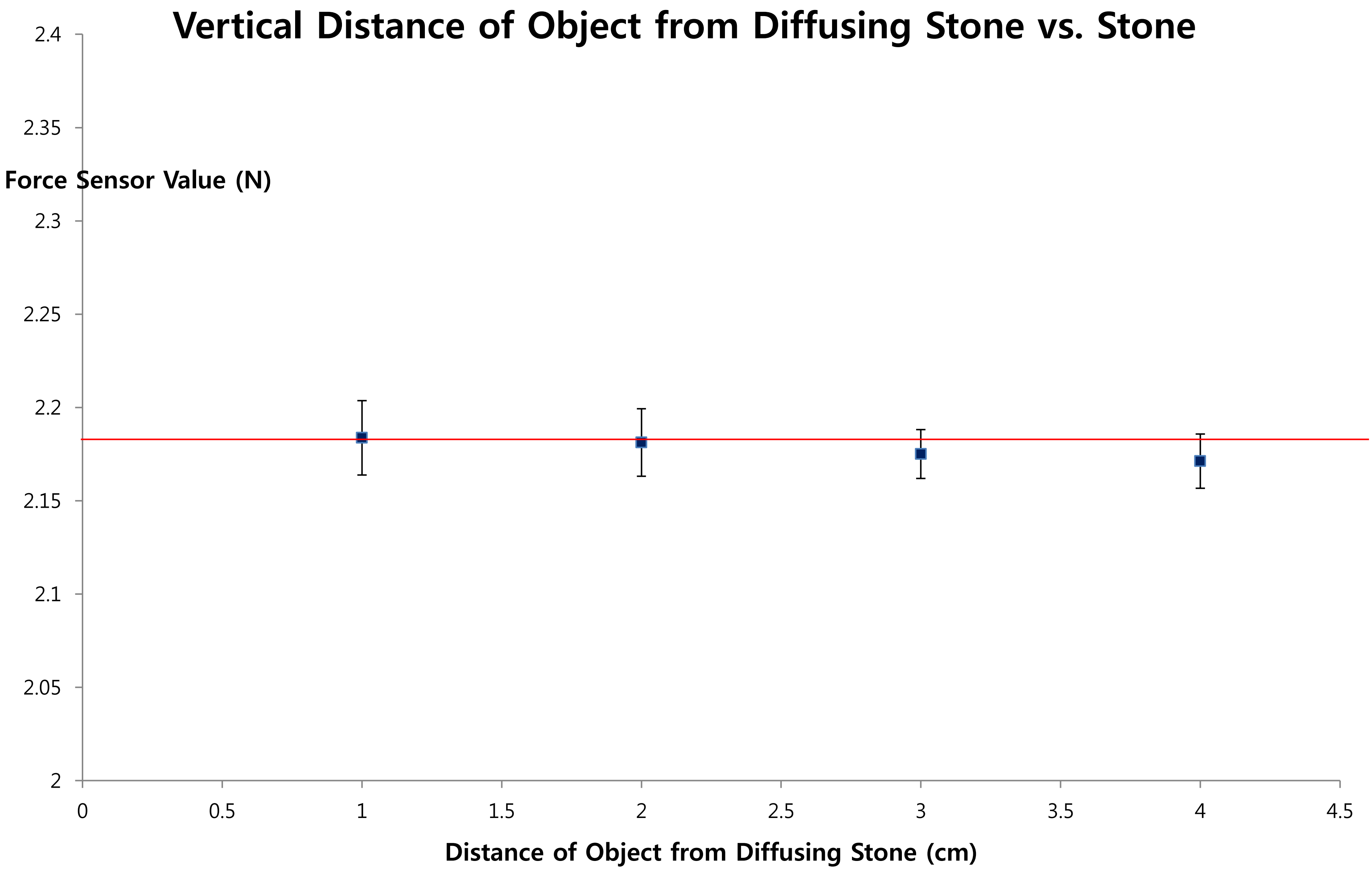
**Equal Distribution of Bubbles**




$$k = \frac{V_{water} - V`}{V_{total} - V`}$$

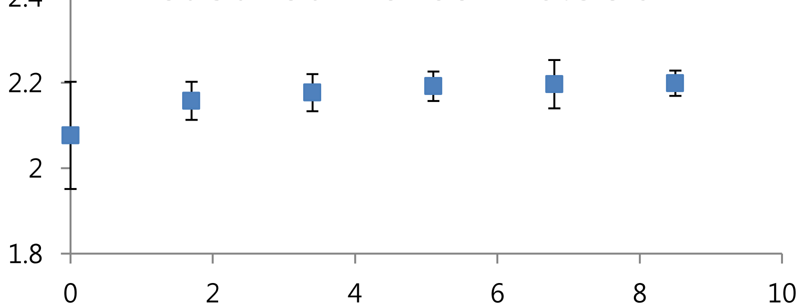
**Subtracted Volume V'**

# Vertical Distance

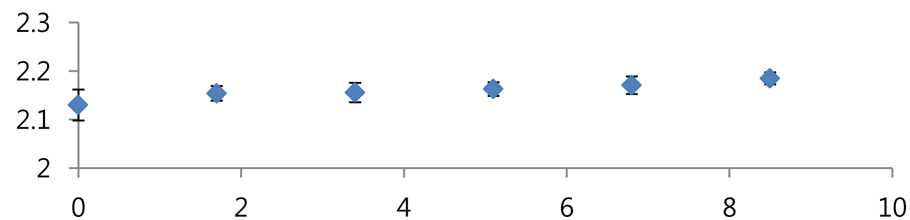


# Standard Deviation

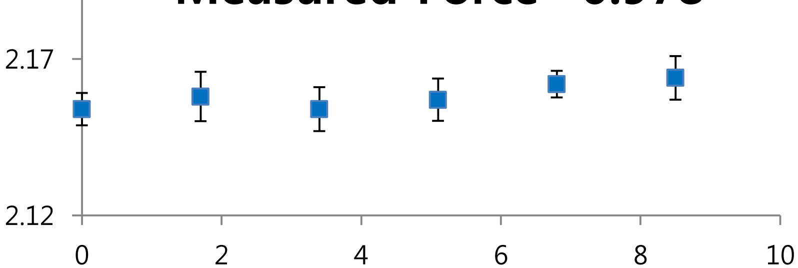
## Measured Force – 0.936



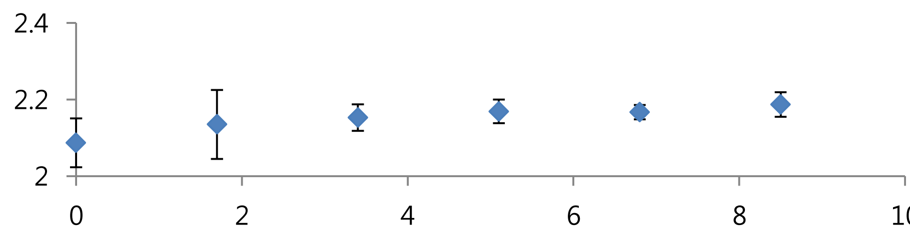

## Measured Force-0.952




## Measured Force –0.978




## Measured Value - 0.947




## Measured Force-0.967