Development of Settling Tube Method to Measure the Particle Size Distribution for the Steam Explosion Accident in the Nuclear Power Plant

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1. INTRODUCTION

The possibility of steam explosion due to energetic and prompt interaction between the molten corium and the water in the nuclear power plant has been widely concerned to quantify its magnitude and to find the way to mitigate the phenomena [1]. Due to the complication and rapid nature of the phenomena, experimental works still need more accurate measurement methods. Especially, the real time observation of the corium-water interaction, instability, steam generation, powdering corium debris needs advanced Tomography methods [2, 3]. As Song et al.[4] pointed based on their experimental observation, the explosive phenomena highly depend on the production of the fine size debris of the molten corium. Instability and local generation of shock waves may be the major causes of the production of the fine debris, which increase the interaction surface area dramatically and the reaction time maybe depend on the penetration time proportional to square root of the particle size.

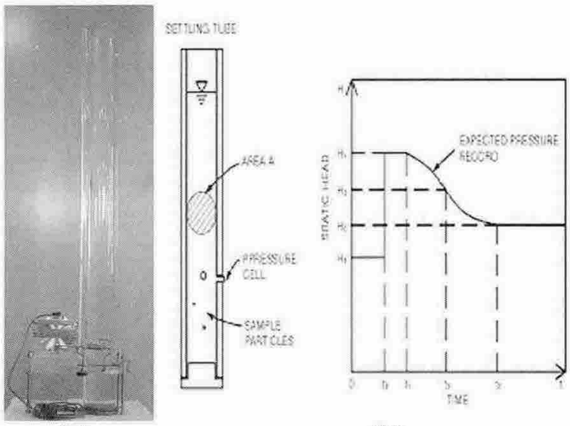
The resultant debris from the explosive reaction can be the most solid fact in the experiment, their size distribution and amount need to be figured by the theoretical model. Pressure and Temperature change can be treated by the global mass and energy balance. Also, the fast propagation of the pressure information through the medium may be reasonably predicted. But to make to more solid understanding the steam explosion phenomena, the transport equation for debris interfacial area concentration need to be developed which should consider the various time scale form the rapid shock attacking, intermediate scale of instability, slow buoyancy rising.

Therefore, the measurement of the size distribution of the fine debris is of importance. However, it is not easy process to classify the particle size and measure their surface area. The present work is mainly focused to develop a convenient way to measure the particle size and its distribution. We employ the force balance between the gravity force and Drag force acting on the free falling particles in the liquid. If we provide a settling tube, the fine debris will settle down in different time scale according to their size.

2. METHODS AND RESULTS

2.1 Settling tube and Signal

The Settling tube is designed as shown In Fig.1(a). Two tubes are vertically installed and connected each other with a valve to balance the water level before experimental work. The pressure difference between two tubes is measured by the micro pressure difference cell. Experimental work is simply made by pouring the fine particles on the top of the settling tube, the particles fall down with their own terminal velocity, so the DP-cell measure the total pressure including the water static pressure and the particles weight. So As shown in Fig.1(b), the rapid rise of the pressure is recorded when the particles are introduced. But when the particles pass the measurement location, DP cell cannot measure the weight of the passing particles. Therefore, the DP signal creases as the particles pass. However, the increase of the water level due to the volume of the particle results in residual DP signals after all particles are settled away from the settling tube.



(a) (b)

Figure1 (a)Schematic Diagrams of the Settling Tube and (b)the pressure head change during the sediments settling

2.2 Theoretical Basis

The Chronological history of pressure change in the settling tube provides information of the particles. When the sample is releases at time t = t0, at the top of water column, the pressure remains constant until t=t1, at which time the largest particles in the sample pass the point where the pressure transducer is located. The pressure head continues to decrease as larger particles settle, and eventually reaches a constant value of H2 at time t=t2, when all particles have settled down below the measuring point.

The weight of the sample, W, is given by

$$W = \gamma(H_1 - H_0)A \qquad (1)$$

The volume of the sediment, V is

$$V = (H_2 - H_0)A \qquad (2)$$

If the fall distance is H_f, the fall velocity of any sediment particle size, w, can be obtained from

$$w = H_f / (t - t_0)\,;\, t_1 < t < t_2 \qquad (3)$$

In order to determine the frequency distribution of fractional weights of sediment sample, the total fall time of the sample, $t_2 - t_1$, was first divided into n equally spaced time intervals, Δt. The corresponding head changes h_i (i=1,...n) were then divided by $H_1 - H_2$, which gave the fractional submerged weights of the sediment sample. A fraction $F(w \geq w_3)$ for which the fall velocity, w, is large than or equal to w_3 can be obtained from

$$F(w \geq w_3) = \frac{H_1 - H_3}{H_1 - H_2} = \frac{\sum_{i=1}^{k} h_i}{\sum_{i=1}^{n} h_i} \qquad (4)$$

The frequency distribution of fall velocities thus obtained in situ now must be used to obtain that of particle sizes. One method to approximate the relationship of fall velocities with particle sizes is assumed that sediment particles are spherical. The fall velocity, w, of a sphere of diameter d is given by

$$w = \frac{4}{3}\frac{gd}{C_D}\frac{\gamma_S - \gamma}{\gamma} \qquad (5)$$

For all particles of any particular shape, the Drag coefficient will conform to a single curve of C_D versus Reynolds number. From the relation established between C_D and Re, one may find either the fall velocity or the sedimentation diameter if the other variable is known. For a known value of w, an approximate particle size d can be estimated as an initial value using a simple formulation such as that derived by Kennedy and Koh[5].

2.3 Experimental Results

A preliminary investigation of the settling-tube method was conducted using glass-bead samples. The commercially available Ballotini solid glass beads with a specific gravity of 2.95 were used. The samples have diameter ranges of 210-325 microns. As shown in Fig.2, the experimental works was performed by settling different amount of the samples form 2 g to 10g but all results are converged into the same trend. This result is a sort of cumulative probability density, so if we take the differentiation with respect to the finer fraction, the probability density function can be easily obtained. The present method can be a useful tool to measure the fine particles associated with the rapid steam explosion in the hypothetical severe accident.

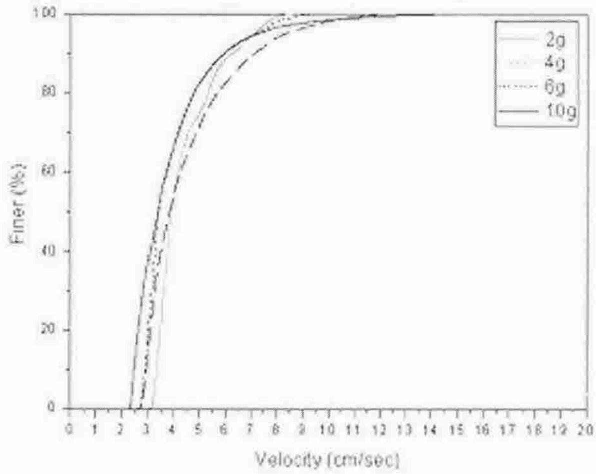


Figure 2. The sample result of finer fraction plotted according to the settling velocity of particles .

3. CONCLUSION

To provide convenient and automatic method in analyze the particle size and distribution of debris after the stream explosion experiment, a settling tube method is developed. The chronological history of the pressure after particle releasing gave the particle size character based on the terminal velocity. The present equipment successfully demonstrates its capability of measuring the particle size distribution. Therefore, it may be useful in the study of severe accident analysis.

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