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On the Direct and Radiated Components of the Collisional Particle Pressure in Liquid-Solid Flows ⋆

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Abstract. In a recent study the collisional particle pressure was measured for liquid fluidized beds and liquid-solid flows. The particle pressure was defined as the 'additional pressure' generated by the presence of the particulate-solid phase in a liquid-solid mixture. The particle pressure generated by collisions of particles was found to be composed of two main contributions: one from pressure pulses generated by direct collisions of particles against the containing walls (direct component), and a second one from pressure pulses due to collisions between individual particles that are transmitted through the liquid (radiated component). This paper presents a summary of the technique to measure the particle pressure and the main results of that study.

Additional experiments were performed to further study each one of the components of the particle pressure. The direct component was studied by impacting particles on the active face of the pressure transducer. The magnitude of the measured impulse was found to be related to the impact velocity, the mass and the size of the impacting particle. By comparing the measurements with the predictions from Hertzian theory, a quantification of the interstitial fluid effects could be obtained. The radiated component was investigated by generating binary collisions of particles in the vicinity of the transducer. The magnitude of the measured impulse was found to be a function of fluid density, particle size and impact velocity. Predictions based on impulse-pressure theory were obtained and compared with the experimental measurements. The model results showed good agreement with the experimental measurements.

Key words: particle pressure, liquid-solid flow.

Abbreviations: PDF – Probability Density Function

1. Introduction

Interest in multiphase flows is motivated by many industrial applications as well as many natural processes. Flows involving solid-fluid mixtures occur in many chemical, petroleum and mining engineering applications. The lack of basic understanding of such mixtures represents an important limitation to better design of devices that handle liquid-solid flows. Even small improvements in the performance these devices could have an important economic impact.

⋆ Dedicated to Leen van Wijngaarden, a true scholar, from whom C.E.B. learnt much about fluid mechanics.

The nature of particulate two-phase flow is complex, and the basic governing equations for such systems are still a matter of current research. Models of dispersed two-phase flows are usually expressed in terms of a set of conservation equations for each of the phases. The momentum conservation equations are coupled through an interaction force term. Difficulties with this approach arise when dealing with the discrete nature of the solid phase. Pressures, P_f, on the dispersed phase and P_p in the discrete phase, are defined and the corresponding pressure gradient terms are included in the momentum conservation equation. While $\partial P_f/\partial x_i$ does not impose any conceptual difficulty, the physical meaning of $\partial P_p/\partial x_i$ is less clear. The particle pressure, or granular pressure, results from the interactions between individual particles and solid boundaries. Whether it contains only particle-to-particle interactions or, in addition, includes indirect interactions through the interstitial fluid is a matter of debate. Many researchers have developed models for the particle pressure [2, 4, 6, 7], but none of these have been corroborated experimentally due to the difficulties encountered in the measurement of the particle pressure.

Recently, Zenit et al. [14] reported measurements of the collisional particle pressure at the walls of fluidized beds and liquid-solid flows using a flush mounted high-frequency-response pressure transducer to collect data on the collision of particles with the active face of the transducer. Two distinct contributions to the particle pressure were identified: a direct component, the result of direct particle collisions against the containing walls; and a radiated component, the result of pressure pulses between particles which are transmitted through the interstitial fluid. The present paper presents a more detailed analysis of these two contributions of the particle pressure.

2. Particle Pressure Measurements

In a recent paper Zenit et al. [14] measured the particle pressure for liquid-solid mixtures. Individual collisions of particles last for only few tens of microseconds, and hence a high-frequency pressure transducer is required. Zenit et al. used a piezoelectric dynamic pressure transducer, capable of responding to changes in pressure in less than 2 microseconds. Experiments were performed in the vertical section of a water loop shown in Figure 1. The pressure transducer was flush-mounted to a side wall of the test section. A high-pass filter eliminated pressure fluctuations below 1 kHz. Thus, only collision-generated pressure pulses were registered. A data acquisition system was programmed to capture individual collision pressure pulses continuously. Vertical gravity driven flows of glass particles and liquid fluidized beds of steel, nylon and glass particles were studied (see Table I). A large number of individual pressure pulses were obtained to calculate the particle pressure. Two different test sections were used with 5.1 and 10.2 cm circular cross-section. The solid fraction, ν, of the mixture was measured using an impedance volume fraction meter [9].

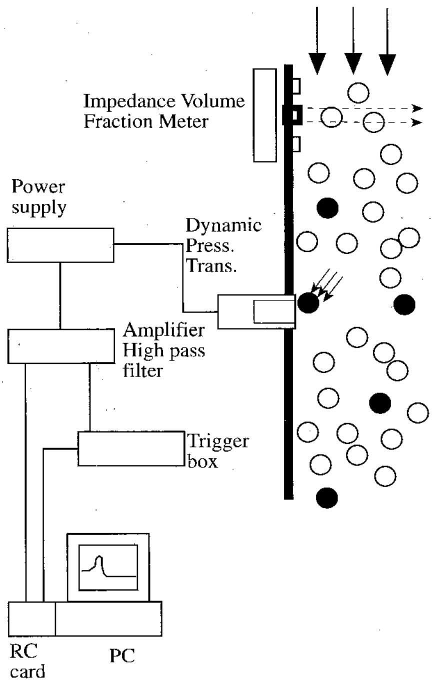

Figure 1. Experimental setup and instrumentation.

Table I. Properties of particles used in experiments.

Material	d_p [mm]	ρ_p/ρ_f	u_t [cm/s]	Re_t
Glass +	2.06	2.54	22.7	452
Glass ×	3.00	2.54	31.8	954
Glass ∗	3.96	2.54	36.8	1338
Glass ∘	6.00	2.54	47.4	2583
Steel ⊕	4.50	7.78	89.6	3665
Nylon ⊗	6.35	1.14	13.6	785
PVC ⊙	3.41[a]	1.43	29.7	440

[a] Equivalent diameter of the cylindrical shape.

The time average particle pressure was calculated as

$$P_p = \frac{1}{T} \sum_{i=1}^{n} I_i, \tag{1}$$

where T is the total time to capture n pressure pulses, each with an impulse, I,

$$I = \int_0^{\tau} P(t)\,\mathrm{d}t, \tag{2}$$