Tendency of adhesive particles on the liquid wall layer in the turbulent flow channel

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ABSTRACT

The experimental investigation and simulation model approach were carried out to investigate the behavior of the fine particles to adhere on the layer of liquid on the wall in gas-solid two-phase flow. Polymethyl methacrylate having two different mean-diameters of 20 µm and of 50µm was used for measurement. By using continuous feeding system, the fine particles were entrained and mixed with the air in the duct. Experiment for solid particle gas with two-phase flow in room temperature was carried out to make a clear turbulent effect for particle adhering behavior to wall side having a high-viscosity liquid layer. These phenomena were also investigated by the simulation model which represented the experimental condition for two-phase flow and using k-ε two equation models for turbulent flow. The experimental result showed that adhered particle quantity depends on particle feeding rate. The result of simulation model also showed the same tendency. The relation of the various particles feeding rate and capture rate were also described.

Key words: adhering phenomena, ash particle, coal combustion, fine particles, k-ε two equation model, Lagrangian method, particle deposition, turbulent flow, two-phase flow, wall of combustion chamber,

ABSTRAK

The experimental investigation and simulation model approach were carried out on the behavior of the fine particles to adhere on the liquid wall layer in gas-solid two-phase flow. Polymethyl methacrylate with two kinds of mean diameters 20 and 50 µm were used for measurement. By using particles continuous feeding system, the fine particles were entrained and mixed with the air in the duct. Experiment for solid particle-gas two-phase flow in room temperature was carried out to make clear turbulent effect for particle adhering behavior to wall side of high-viscosity liquid layer. These phenomena were also considered by the simulation model which represented the experimental condition for two-phase flow by k-ε two equation models for turbulent model. The experimental result showed that adhered particle quantity depends on particle feeding rate. Simulated result also showed same tendency. The relation of the various particles feeding rate and capture rate were shown.

Kata kunci: .

1. INTRODUCTION

Turbulent gas flows with solid particles are common in several processes of the solid fuel combustor such as the coal fired combustion chamber. As the temperature of the combustion chamber is increased, the ash particles melt and sticking on the wall tube surface. Ash particles will then adhere to the melting ash layer, more and more and increase the thickness of melting ash layers. The heat transfer rate is thus decreased

since this melting ash conductivity is lower than that of chamber wall materials.

Behaviors of the ash particles interact with the fluid flow and make collision to each other. Simulation model, experiment or combination of both approaches will be effective to understand the ash behaviors. However, the development of simulation model with real condition is difficult without knowing the phenomenological aspects.

The objectives of this study are:

- to understand the interaction between the melting ash particle and the wall, and
- to construct simulation model including coalescence of each melting ash particle, boundary behavior of melting ash.

This paper describes the result of experiment regarding tendency of particle deposition on high-viscosity liquid layer in two phase-flow channel.

2. SWIRLING EFFECT AS INERTIAL FORCE FOR PARTICLE MOTION

The effective control of combustion needs a standard to judge condition whether the melting ash adheres to the wall side or not. This problem will be more serious in the future when high-ash-content coal (such as semi-bituminous and bituminous coal) remains. ***Although low-ash-content coal also remains now fortunately*.** **Membingungkan! Please rewording**

The present judgment depends on the ash properties only, for example ash contents, ash viscosity and melting point without considering particle's dynamic behavior and flow field in the furnace. The various driving force as control mechanism of particle motion near the boundary layer are shown in **Fig.1.**

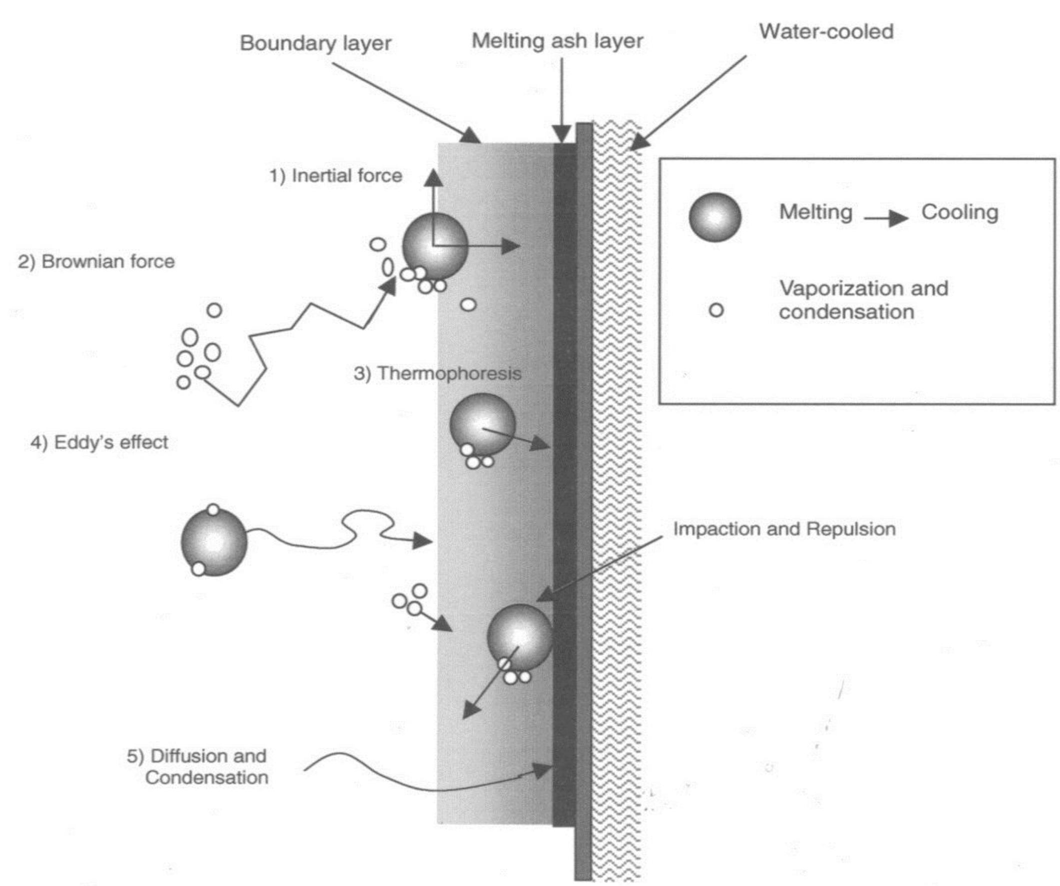


Fig.1: Control mechanism of the particle motion near the boundary layer [1]

Swirling effect appears as inertial force for particle motion,

1) Brownian motion is effective in the condition of fine particle
2) (diameter <φ1μm) and small effect of other driving forces,
3) thermo-phoresis is effective since the temperature gradient between combustion gas inside the furnace and water-cooled wall,
4) the eddy motion is important in turbulent flow and
5) the diffusion and condensation are considered in the heating condition that temperature is over melting point of ash particle.

The experiment are set and the results are used to verify the accuracy of the simulation model used.

3. EXPERIMENTAL SETUP

Experiment was performed in the facility shown in **Fig 2**. The acrylic resin duct with 110 x 110 mm and 4m length on the horizontal position was used. The flow rectifier was installed on the duct.

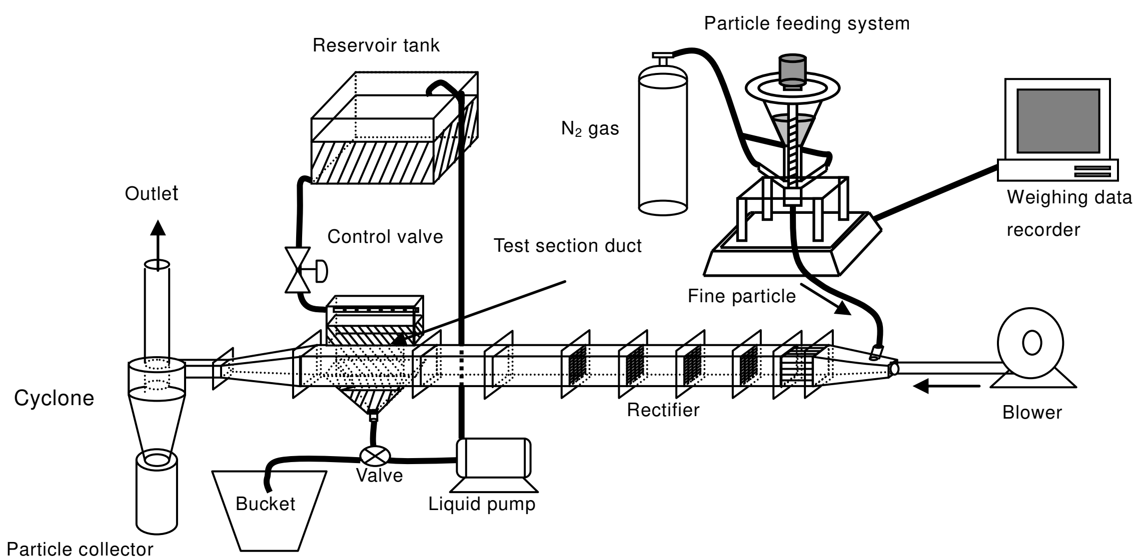


Fig 2. Schematic diagram of experimental apparatus.

The apparatus has four component parts.

- First part is the blower system which is use to supply the air into the duct.
- Second part is the screw feeding system with the weighing data recorder and using N_2 gas to carry the particles to the duct.
- Third part is the liquid feeding system and the liquid pump for circulation. In this case, the liquid makes the thin layer with one side of wall (440 cm^2).
- Fourth part is the cyclone system for the particle collection after the test section.

Jelaskan Millet-jelly and water mixture pada salah satu part diatas

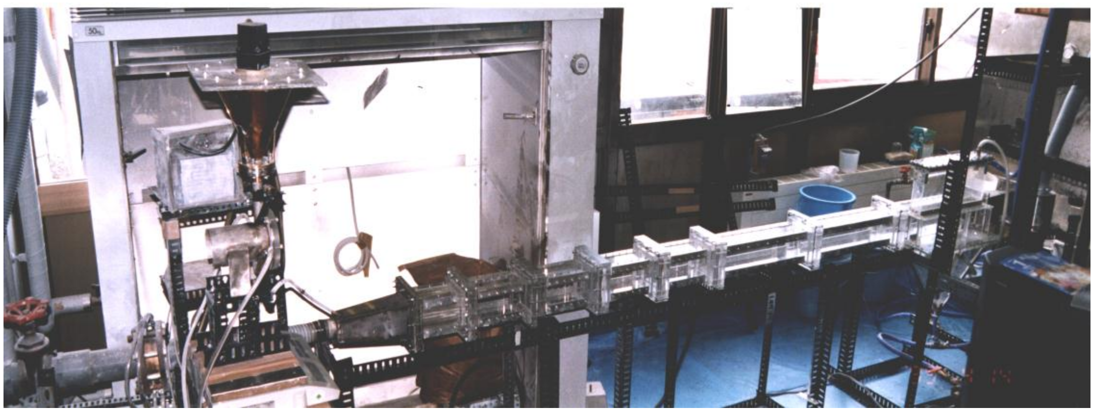
Procedures of the experiment are as follows.

- Millet-jelly and water mixture flow can be controlled by the control valve from reservoir tank, circulated by the liquid pump and the air driven by blower through extensive flow conditioning before entraining particles in the duct.
- After a stable condition is reach, the valve of liquid was adjusted to the bucket direction.
- At the same moment, the fine particles were entrained to the duct and data of the weight particles per unit time was recorded. The weighing data recorder is using the weight loss data.
- The rectifier kept the particles-fluid flow distribution uniform in the duct.

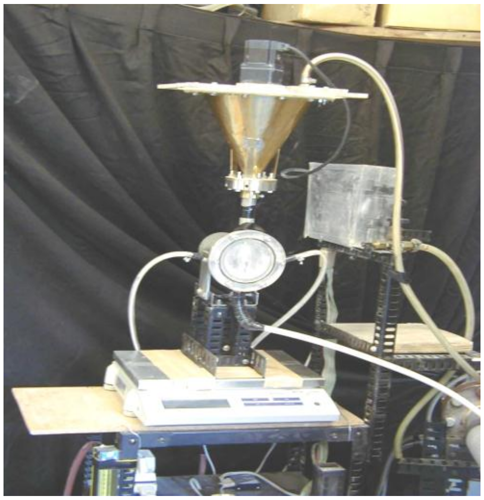
The experiments have been performed in an open-loop system, because the liquid flow can not covered by the liquid–particle separation velocity. **Tak jelas**

Table 1. Experimental condition

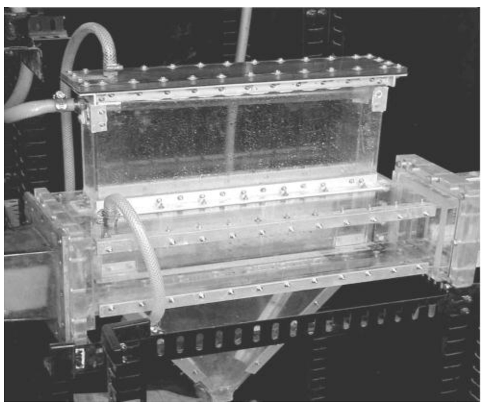
Particle Mean diameter [μm] Density [kg/m^3]	Polymethyl Methacrylate 20 and 50 1200
Fluid Velocity [m/sec] Flow rate [Nm^3/hr] Re number	Air 5.5 225 40,000
Liquid Flow rate [l/min] Viscosity [Pa･s]	Millet-Jelly Mixing Water 7.5 0.00659



Picture of experimental apparatus



Picture of Particles Feeding System



Picture of Test Section of Adhesive Particles Capture to the Liquid Wall Layer

4. SIMULATION MODEL

The observed field is the test section of duct (110mm x 110mm x 500 mm) with x, y and z coordinates as shown in **Fig. 3.**

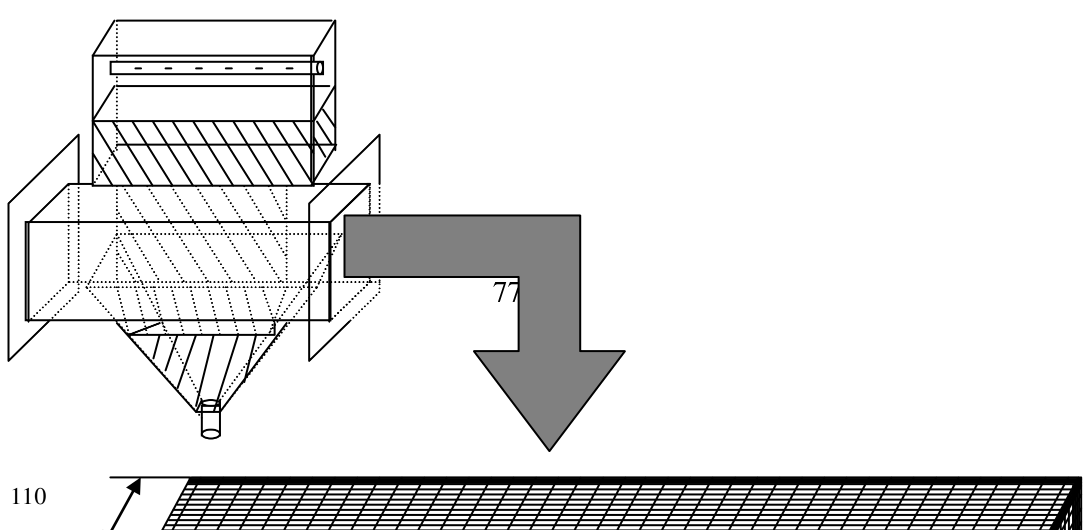


Fig. 3: Grid Arrangement of Test Section and Calculation Domain.

Low Reynold Number k-ε two equations model was used for turbulence flow of gas phase. Transport equation of gas phase is shown as:

$$\frac{\partial}{\partial x}(\rho U\phi)+\frac{\partial}{\partial y}(\rho V\phi)+\frac{\partial}{\partial z}(\rho W\phi) = \frac{\partial}{\partial x}\left(\Gamma_{\phi}\frac{\partial \phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_{\phi}\frac{\partial \phi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma_{\phi}\frac{\partial \phi}{\partial z}\right)+S_{\phi}+S_{d\phi} \tag{1}$$

where φ and Γ_{φ} is dependent variables and turbulent diffusion coefficient, respectively as shown in **Table 2.**

C_{μ}, $C_{\varepsilon 1}$, $C_{\varepsilon 2}$, σ_k, σ_{ε}	is model constant
k	*is t*urbulent energy [m^2/s^2]
P	*is p*ressure [Pa]
U, V, W	*is v*elocity component [m/s]

x, y, z	*is c*oordínate [m]
X_1	is quantity of initial particle feeding [g]
X_2	is quantity of remained particles in duct [g]
X_3	is quantity of remain particle in the cyclone [g]
X_4	is quantity of particle exhausted from apparatus [g]
ε	is Eddy dissipation rate [m^2/s^3]
η	is particle capture rate [%]
μ	is viscosity [Pa·s]
ρ	is density [kg/m^3]

Table 2. Source term and turbulent Diffusion coefficients for gas phase governing equations.

Conservation Equation of ϕ		Γ_ϕ	S_ϕ
Mass	1	0	0
Velocity Component	U	μ_{eff}	$\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial W}{\partial x}\right)-\frac{\partial P}{\partial x}$
	V	μ_{eff}	$\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial U}{\partial y}\right)+\frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial V}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial W}{\partial y}\right)-\frac{\partial P}{\partial y}$
	W	μ_{eff}	$\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial U}{\partial z}\right)+\frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial V}{\partial z}\right)+\frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial W}{\partial z}\right)-\frac{\partial P}{\partial z}$
Kinetic Energy	k	$\frac{\mu_{eff}}{\sigma_k}$	$G_k - \rho\varepsilon$
Dissipation Rate	ε	$\frac{\mu_{eff}}{\sigma_\varepsilon}$	$\frac{\varepsilon}{k}\left(C_{\varepsilon 1}G_k - C_{\varepsilon 2}\rho\varepsilon\right)$

$$G_k = \mu_{eff}\left\{2\left[\left(\frac{\partial U}{\partial x}\right)^2+\left(\frac{\partial V}{\partial y}\right)^2+\left(\frac{\partial W}{\partial z}\right)^2\right]+\left(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial x}\right)^2+\left(\frac{\partial W}{\partial y}+\frac{\partial V}{\partial z}\right)^2+\left(\frac{\partial U}{\partial z}+\frac{\partial W}{\partial x}\right)^2\right\}$$

C_μ	$C_{\varepsilon 1}$	$C_{\varepsilon 2}$	σ_k	σ_ε
0.09	1.44	1.92	1.0	1.3

Particle motion was calculated by Lagrangian method.

In this case, the momentum equations include lift forces of rotary force and Saffman force **[2]** because of consideration of detail phenomena of particle motion near wall side. Particle-particle collision model is considered by O'Rourke's model **[3].**

Particle-wall collision model is also considered. The coupling between gas phase and particle phase is considered by PSI-CELL model **[4]**

Particle to particle collision effect and particle to the wall interaction effect were considered **[5].** The Wall function is used for boundary condition.

5. EXPERIMENTAL RESULT AND DISSCUSION

Velocity distribution of gas phase is shown in **Fig 3.**

The boundary condition of wall side was represented by the wall function, see **Fig. 4.** *This result is almost same as the simulated result of particle-laden flow with small particle feeding rate.* **Tak jelas maksudnya**

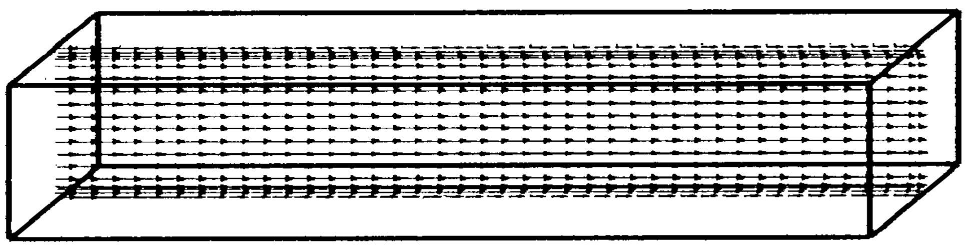


Fig. 4: Calculation Velocity Vectors of Single Phase Flow

Comparison of the calculated velocity distribution and with the experimental data result are shown in **Fig. 5.** The velocity distribution near the wall almost have the same tendency.

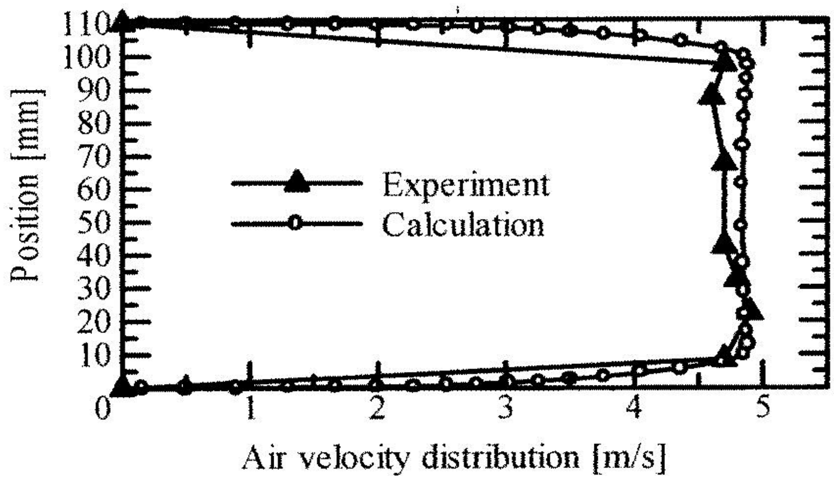


Fig. 5: Comparison between air velocity distribution determined by experiment and calculation.

Particle trajectories in the duct is shown in **Fig. 6**. Particle trajectories in the condition of particle diameter: φ 20μm and particle feeding rate was adjusted 10 to 70 g/min. Particles proceed linearly from inlet to outlet. In this case, few particles adhere to wall side. Particle of 10 g/min feeding rate corresponds to about 3×10^7 particles pass in the duct per second. It is thought that number of particles in the calculation is too small to predict the real condition.

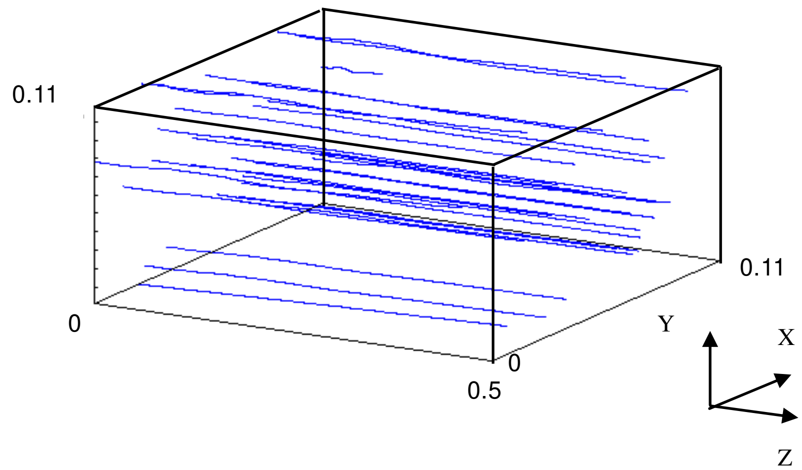


Fig. 6: Particle trajectories in the duct.

Particles proceed linearly from inlet to outlet.

A layer of a high-viscosity liquid covered the wall side in the experiment. It is assumed that if a particle contacts with the wall side, adhesion of the particle will occur immediately. Particles pass the duct straightly from inlet part to outlet part. It's difficult to measure the quantities of captured particle in liquid, we use another method. After finishing the experiment, the remain particle in the duct is collected. The rate of captured particle in the liquid is calculated from the difference value between initial feeding particle weight and remained particle weight in the duct. The capture rate of particle was calculated from the equation (2):

$$\eta = \frac{X_1 - X_2 - X_3 - X_4}{X_1 - X_2} \times 100 \qquad (2)$$

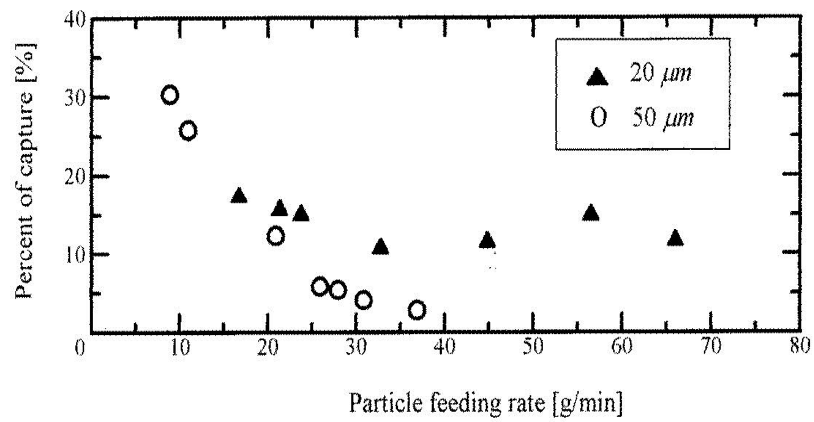


Fig. 7: Variations of particle capture rate with particle feeding rate

Predicted the particle capture rate by calculation is used with assumptions.

Membingungkan.

The calculation of particles in the duct is difficult, because of the need of a large memory size data recording and much time are needed.

In order to overcome this condition, a representative particle is used for calculation, see **Fig. 7** that shows variations of particle capture rate with particle feeding rate.

The particles with 20 μm diameter and 50 μm show almost the same tendencies with that of capture particles. Particle capture decreases with an increase in particle feeding rate. The particles with a bigger diameter has lower capture rate then that of smaller particles diameter, this means the rate of captures was under influences of the number and the density of particle.

Fig. 8 shows a comparison of capture tendency between experiment and calculation. The calculation results show the same tendency even though its feeding rates vary.

On the other words, if the number of particles increases, the calculation result can be close to the experimental result.

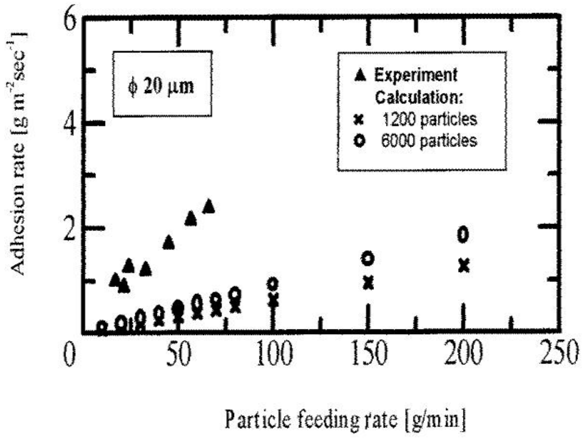


Fig.8: Variations of particle adhesion rate (in gram m3 …..) with particle feeding rate (gram/minute). Satuan tidak jelas, saran tambahkan

6. CONCLUDING REMARKS AND SUGGESTION

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