HYDRODYNAMICS OF THE ROTATING CONE PYROLYSIS REACTOR

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ABSTRACT

The flow of nearly spherical mono-sized PVC powder in a cold-flow rotating cone reactor was investigated under variation of the particle diameter (140 - 780 µm) and the cone rotational speed (up to 1800 rpm). The gas flow showed a marked influence on motion of particles smaller than 200 µm. A mathematical model is presented using a single particle description, and a gas flow description near the wall according to the universal velocity profile [1]. The experimentally observed residence time of the particles inside the reactor is typically in the order of 0.1 second.

INTRODUCTION

The rotating cone reactor is a newly developed reactor for flash pyrolysis of biomass with negligible char formation. In the novel pyrolysis reactor rapid heating and a short residence time of the solids can be realised. Biomass materials like sawdust, rice husks or even olive stones can be pulverised and fed to the rotating cone reactor. Flash heating of the biomass will prevent coke forming cracking reactions. Since no carrier gas is needed (cost reducing) the pyrolysis products will be formed at high concentrations. Moreover, thermal quenching of the gas phase is possible which reduces the amount of secondary tar decomposition reactions. The particles remain close to the rotating cone wall and experience a high heat transfer rate. The particle free core of the cone is radiation transparant and uniform particle heating is expected to occur.

EXPERIMENTAL

PVC particles are used as a model solid. They leave the feeding tube at the bottom of the rotating cone reactor and enter an impeller which is attached to the rotating cone to give the particles a centrifugal acceleration before they reach the cone wall at the bottom of the reactor. Because of the rotational motion of the cone the particles are swept out of the reactor following a spiral path along the cone wall. An endoscope with camera is used to record the particle motion. At a shutter speed of 1 ms, the particle movement can be seen as streaks of a few mm length. This length is directly proportional to the local particle velocity. A high photographic contrast is obtained with PVC powder because of its white color on a black background. PVC powder has a density of 1100 $kg.m^{-3}$ which is comparable to biomass density.

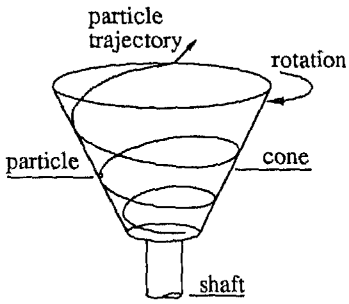

Figure 1. The cone.

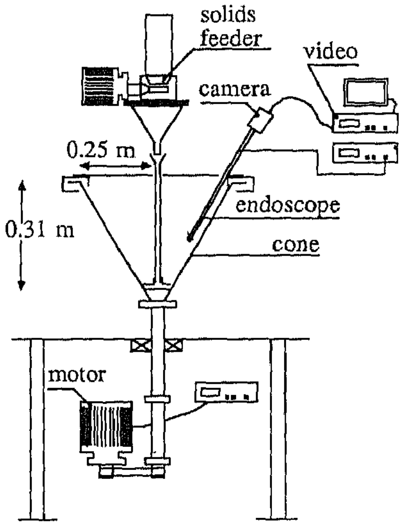

Figure 2. The experimental set-up.

MODEL DEVELOPMENT

The mathematical model which describes the particle motion consists of two parts, the single-particle and gas-phase flow description. The particle motion is calculated from a force balance which is applied to a particle when it moves in free flight between two successive wall collisions. The collisions between particle and the cone wall are assumed to be elastic. It has been assumed that the turbulent gas phase can be described by the "law of the wall" [1]. The velocity profile of a turbulent flow near a wall is independent of the macroscopic flow geometry and is based on microscopic turbulence behaviour.

Single particle description

The force balance on a particle yields:

$$m_p \cdot \frac{d\,\underline{v}_p}{dt} = \underline{F}_d + \underline{F}_g \tag{1}$$

with

$$\underline{F}_g = m_p \cdot g_z \cdot \underline{e}_z \tag{2}$$

$$\underline{F}_d = C_d \cdot \frac{\pi}{4} \cdot d_p^2 \cdot \frac{1}{2} \cdot \rho_f \cdot |\underline{v}_f - \underline{v}_p| \cdot (\underline{v}_f - \underline{v}_p) \tag{3}$$

The elastic collision requires that:

$$\underline{v}_p(2) = (\underline{1} - \underline{nn}) \cdot \underline{v}_p(1) \tag{4}$$

Gas phase description

Experimental observation showed that the gas phase in the core (5) of the cone had an angular speed of 1/4 of that of the rotating cone. When using the universal velocity profile two other layers have to be considered, the logarithmic layer (6) and the surface-roughness layer (7). The viscous sublayer is absent because of the wall roughness. The velocity profile is described by:

$$v_f = \frac{1}{4} \cdot \omega . r \tag{5}$$

$$v_f = \omega . r - \frac{1}{4} \cdot \omega . \delta . \ln \frac{R - r}{(h/30)} \tag{6}$$

$$v_f = \omega . r - \frac{1}{4} \cdot \omega . \delta . \ln 30 \tag{7}$$

$$\delta \text{ from } \frac{1}{3} . \delta . (\ln \delta + 10) = R \tag{8}$$

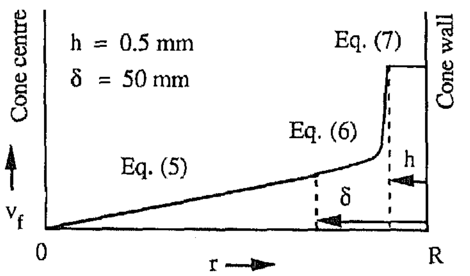

Figure 3, Assumed profile of the angular gas velocity.

RESULTS

Measurements have been carried out for various different particle diameters and cone rotational speeds. From these measurements, the residence time of the particles versus the cone rotational speed is obtained, as can be seen in figure 4. Calculations have been carried out for the conditions of the experimental set-up, based on the theory outlined above. Results of the calculations are compared with the experimental results and show a reasonable agreement, see figure 5.

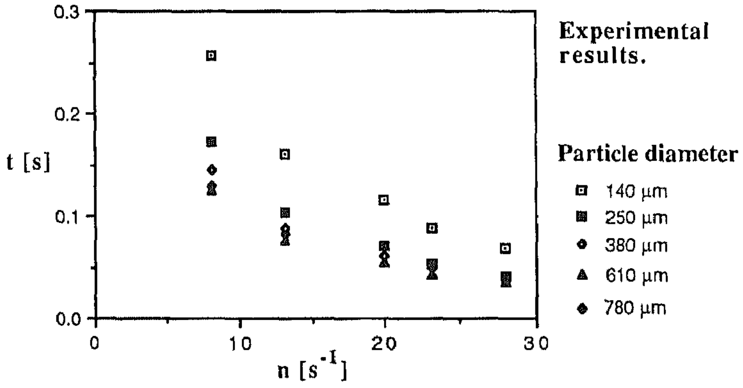

Figure 4, The particle residence time versus the cone rotational speed.

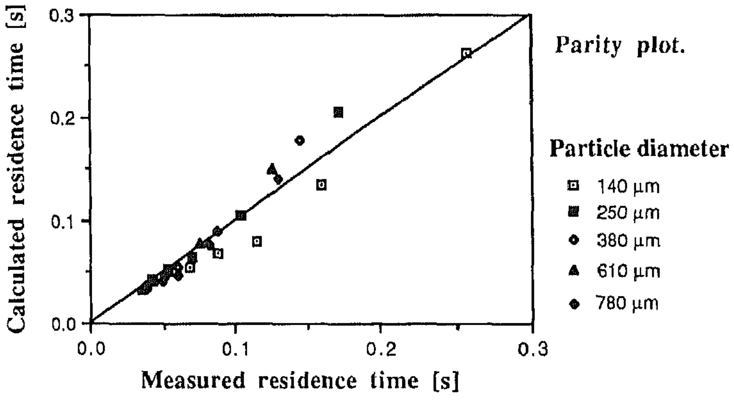

Figure 5, The particle residence time versus the cone rotational speed.

CONCLUSIONS

- Particles larger than 400 μm seem to be unaffected by the viscous forces, and the residence time of the particles is almost independent of the particle diameter.
- If the particle diameter is smaller than 200 μm the viscous forces become dominant and the particle residence time is strongly dependent on the particle diameter.
- The particle residence time versus the cone rotational speed can roughly be described by $t = 1.3/n$.

Future experiments will involve heat transfer to, and pyrolysis of biomass particles.

Parameters used

Gravitational constant g	9.81	[$m.s^{-2}$]
Fluid phase density ρ_f	1.3	[$kg.m^{-3}$]
Particle density ρ_p	1100	[$kg.m^{-3}$]
Surface roughness h	$0.5.\ 10^{-3}$	[m]
Cone topangle	60	[°]
Cone height	0.310	[m]
Impeller diameter	0.072	[m]
Fluid phase viscosity η_f	$1.8.\ 10^{-5}$	[Pa.s]
Initial particle-		
radial position r_o	0.072	[m]
velocity $v_{\phi,o}$	$\omega.r_o$	[$m.s^{-1}$]
wall distance	10^{-3}	[m]

Symbols

C_d	Sphere friction	[-]
d_p	Particle diameter	[m]
$\underline{F}$	Force	[N]
g	Gravitation	[$m.s^{-2}$]
h	Surface roughness	[m]
m_p	Particle mass	[kg]
n	Cone rotation	[s^{-1}]
$\underline{n}$	Surface normal vector	[-]
r	Local radius	[m]
R	Wall radius	[m]
$\underline{v}$	Velocity	[$m.s^{-1}$]
δ	Logarithmic layer	[m]
ω	Cone angular speed	[$rad.s^{-1}$]

REFERENCES

1. R.B. Bird, W.E. Stewart and E.N. Lightfoot
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