Table 1. Comparison of calculated values with experimental ones for amount of PVA transferred at and near drying surface

C_i [%]	L [cm]	T.N.D. [—]	Experimental values $\times 10^6$ [kg]	Calculated values $\times 10^6$ [kg]
0.475	5.9	1	1.3	1.7
0.94	5.0	1	37.3	45.9
0.94	6.3	1	50.5	60.6
0.94	6.3	5	51.6	60.6

T.N.D.: Total number of dissolutions.

Nomenclature

C	= concentration of PVA in solution	[—]
C_e	= plateau adsorption value	[—]
C_i	= initial additive ratio of PVA to talc	[—]
L	= length of agglomerate	[m]
M_a	= amount of PVA existing in solution among talc particles before drying	[kg]
M_d	= amount of PVA transferred at and near drying surface	[kg]
w_c	= critical moisture content	[—]
w_i	= initial moisture content	[—]
Γ	= adsorption amount of PVA on talc	[—]

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PERFORMANCE OF A ROTATING FLUIDIZED BED

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Introduction

Centrifugal fluidization is a relatively new fluidization concept which has the advantages of higher gas flow rate, compactness, reduced particle loss by elutriation and flexibility of operation as compared with conventional fluidization.[1]

It is expected that centrifugal fluidized beds (CFB's) will be applied in many fields. Works on CFB's were published by Gelperin *et al.*[3] and Hatch *et al.*[5] in 1960. Other papers were published during the 1970's and 1980's in U.S.A., USSR, Great Britain and other countries. The majority are concerned with applications to coal combustion, gasification, classification, food processing, and drying. It appears that relatively little effort has been spent in investigating CFB from fundamental points of view.

The present paper describes some of the experimental results obtained by the present authors by using a horizontal rotating fluidized bed with different particle densities and size distributions to determine the minimum fluidization velocity, maximum bed pressure drop, variation of pressure drop with rotating speed, and bed expansion.

1. Experimental Apparatus and Procedure

A sketch of the centrifugal fluidized bed and associated equipment is given in **Fig. 1**.

The bed rotated horizontally. The rotor was of 144 mm inside diameter (ID) and 10 or 20 mm wide. Its rotational speed ranged from 400 to 800 r.p.m.
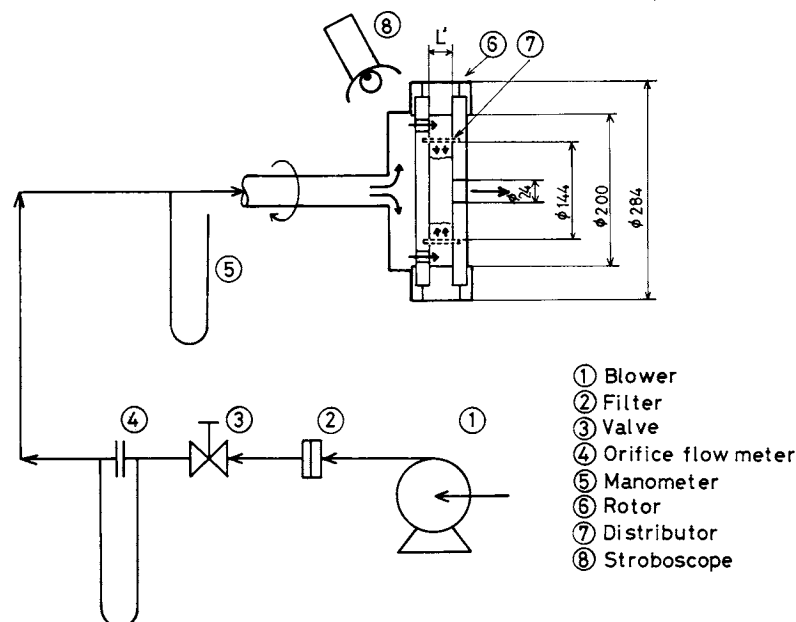
Fig. 1. Scheme of experimental apparatus.

① Blower
② Filter
③ Valve
④ Orifice flow meter
⑤ Manometer
⑥ Rotor
⑦ Distributor
⑧ Stroboscope

The air distributor was a cylindrical sintered metal element of 40 μm mean pore size. Both end walls were of transparent acrylic resin for ease of viewing.

Experiments were conducted using glass beads, magnesia clinker, silica sand, and polyethylene powder. Their physical properties are given in **Table 1**.

The powder was charged in the rotor; the amount of powder ranged from 0.025 to 0.2 kg. Then air was admitted into the chamber at a flow rate up to 1.5 m/s at the inner surface of the distributor. The pressure drop, bed expansion, and particle elutriation rate were measured at various combinations of rotating speed, air flow rates, and charged weights. The voidage was determined from photographs of the bed height.

2. Experimental Results and Discussion

Figure 2 presents the bed pressure drop as a function of the air velocity. Unlike a conventional fluidized bed, the pressure drop in the centrifugal fluidized bed does not remain essentially unchanged; it attains maximum value at a certain fluidizing velocity or, more specifically, at u_{mf}. A further increase in gas velocity beyond u_{mf} results in a slight decrease in pressure drop.

Assuming rigid-body rotation, the maximum pressure drop has been given very approximately as[3]

$$\Delta P_{max} = W_0 \omega_0^2 / (2\pi L') \qquad (1)$$

Our derivation of pressure drop in the centrifugal fluidized bed resulted in

$$\Delta P = \frac{\int_{r_0}^{r_i} 2\pi \rho_p (1-\varepsilon) r^2 \omega_0^2 dr}{2\pi r_0}$$

Table 1. Physical properties of tested materials

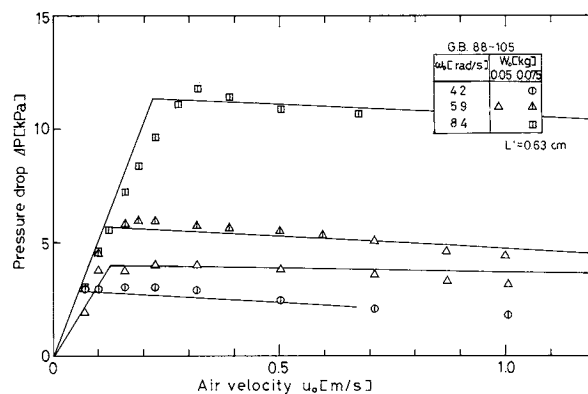|	Density [g/cm³]	Mean size [μm]
Glass beads	2.41–2.49	67, 95, 140
Magnesia clinker	3.61–3.65	87, 124, 140
Silica sand	2.67–2.70	186, 244, 338

Fig. 2. Variation of pressure drop with air velocity.

$$= \frac{1}{3} \rho_p (1-\varepsilon) \omega_0^2 \frac{(r_0^3 - r_i^3)}{r_0} \qquad (2)$$

$$W_0 = \pi \rho_p (1-\varepsilon)(r_0^2 - r_i^2) L' \qquad (3)$$

Substitution of Eq. (3) in Eq. (2) gives

$$\Delta P = \frac{W_0 \omega_0^2}{2\pi L'} \left(\frac{2}{3} \frac{1-R^3}{1-R^2} \right) \qquad (4)$$

where $R = r_i / r_0$

$$R = \sqrt{1 - W_0/(\pi \rho_p (1-\varepsilon) L' r_0^2)} \qquad (5)$$

The decrease in pressure drop can be explained by this

equation. The calculated maximum pressure drop, $(-\Delta P_{maxc})$, which is obtained at $\varepsilon = \varepsilon_{mf}$, and the experimental values are compared in **Fig. 3**.

The calculated and experimental minimum fluidization velocities in a centrifugal fluidized bed[6,7] are compared in **Fig. 4**; the calculated values were obtained by resorting to the Kozeny-Carman or the Ergun equation; thus,

$$u_{mf} = \Delta P_{max} K / \mu r_0 \ln (r_0/r_i) \qquad (6)$$

where $K = \varepsilon^3 / [5 S_v^2 (1-\varepsilon)^2]$

$$u_{mf} = (B - \sqrt{B^2 - 4AC})/2A \qquad (7)$$

in which

$$A = \frac{1.75 D_p \rho r_0^2}{1-\varepsilon} \left(\frac{1}{r_0} - \frac{1}{r_i} \right)$$

$$B = 150 \mu r_0 \ln (r_0/r_i)$$

$$C = \varepsilon^3 D_p^2 \Delta P_{max}/(1-\varepsilon)^2$$

The bed expansion ratio, N_v, is defined as[2,4,9]

$$N_v = \frac{V}{V_0} \frac{1-\varepsilon_{mf}}{1-\varepsilon_f} \qquad (8)$$

Note that the expansion ratio is proportional to the dimensionless air velocity u_0/u_{mf}, as can be seen in **Fig. 5**.

It has been correlated empirically as

$$\frac{1}{N_v} = \exp\left\{ -\beta [(u_0/u_{mf})^m - 1] \right\} \qquad (9)$$

Eqs. (4), (5), (8) and (9) were used to determine the profile of pressure drop as a function of air velocity. The computed values are in good agreement with the experimental results as shown in Fig. 2.

Conclusion

The performance of a centrifugal fluidized bed was investigated both experimentally and theoretically. The pressure drop profiles obtained are substantially different from those in the literature. The results of the present work should be applicable to the design of a centrifugal fluidized bed and to the determination of its operating conditions.

Nomenclature

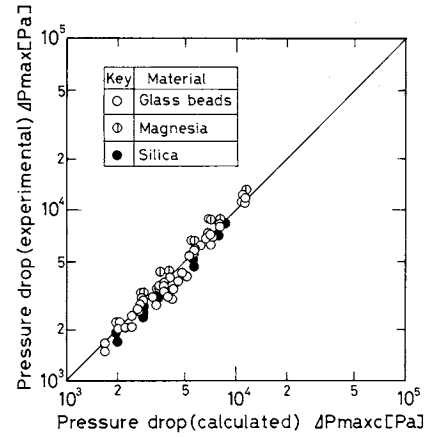|		
A, B, C	= constants for Eq. (7)	[—]
D_p	= particle diameter	[m]
g	= gravitational acceleration	[m·s^{-2}]
K	= permiability	[m^2]
L'	= effective width of distributor	[m]
m	= constants for Eq. (9)	[—]
N_v	= bed expansion ratio	[—]
$-\Delta P$	= pressure drop	[Pa]
$-\Delta P_{max}$	= maximum pressure drop of bed	[Pa]
$-\Delta P_{maxc}$	= maximum pressure drop calculated	[Pa]
r_i	= inner radius of bed	[m]

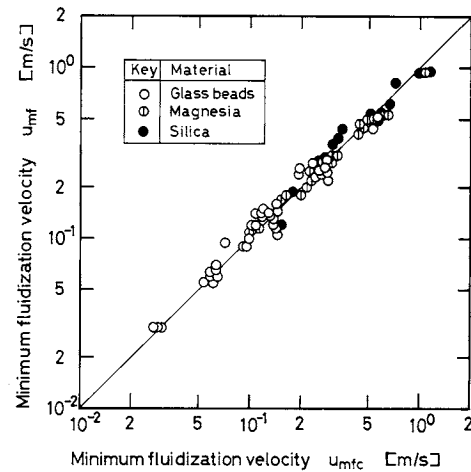**Fig. 3.** Comparison of experimental and calculated pressure drop.

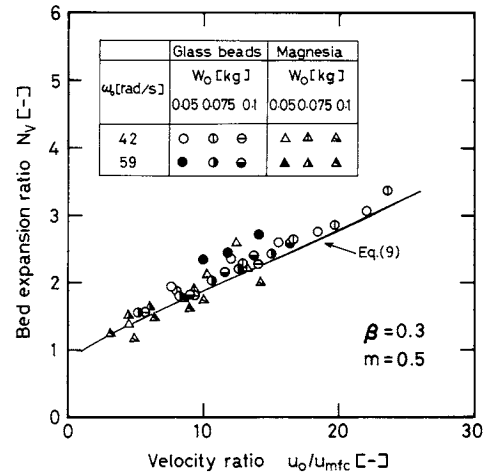**Fig. 4.** Comparison of experimental and computed results of u_{mf}.

Fig. 5. Bed expansion with air velocity.

r_0	= outer radius of bed	[m]
R	= dimensionless radius $R = r_i/r_0$	[—]
S_v	= specific surface area	[m^{-1}]
u_0	= superficial gas velocity	[m·s^{-1}]
u_{mf}	= minimum fluidization velocity	[m·s^{-1}]
V	= bed volume	[m^3]

V_0	= bed volume at $u = u_{mf}$	[m³]
v_{ti}	= terminal velocity at $r = r_i$	[m·s⁻¹]
W_0	= bed mass	[kg]
β	= constant for Eq. (9)	[—]
ε	= void fraction	[—]
ε_f	= void fraction in fluidized bed	[—]
ε_{mf}	= void fraction at $u = u_{mf}$	[—]
ρ	= fluid density	[kg·m⁻³]
ρ_p	= particle density	[kg·m⁻³]
μ	= viscosity	[Pa·s]
ω_0	= angular velocity	[rad·s⁻¹]

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A NOTE ON SYNTHESIS OF THERMOCHEMICAL CYCLES FOR REDUCING CARBON DIOXIDE

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Introduction

It is widely known that the content of carbon dioxide is increasing in the earth's atmosphere. The earth is becoming warmer by the so-called "greenhouse effect" caused by carbon dioxide emitted mainly from fossil fuel combustion. Carbon monoxide can be one of the major raw materials for "C_1-chemistry" in the very near future. If a practical process to convert carbon dioxide to monoxide is established, the burden material can be raised to a new chemical feedstock as well as an energy resource.
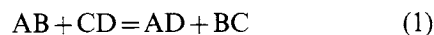
Direct dissociation of carbon dioxide occurs at temperatures higher than 3350 K. A thermochemical cycle is therefore needed to overcome the free energy of dissociation at lower temperatures.[2] Bamberger and Robinson[1] have proposed a reaction cycle composed of cerium oxide and sodium phosphate. The cycle is so complex that it consists of six succeeding reactions. Martin[3] has attempted to use solar energy for reducing carbon dioxide. The process comprises the reduction of carbon dioxide by metals and the decomposition of the resultant metal oxides into metals and oxygen at extremely high temperatures. The reaction sequences have been chosen on the basis of thermodynamic data only, without reaction kinetic information. Therefore, the feasibility of the proposed cycles may be very poor.

In this paper, thermochemical cycles for reducing carbon dioxide to carbon monoxide are synthesized in a systematic way by making use of directed graphs, and the feasibility of these cycles is discussed from the standpoint of chemical thermodynamics and chemical reaction kinetics.

1. Synthesis of Chemical Reaction Cycle

A chemical reaction described by the following reaction formula may be represented by a directed graph as illustrated in **Fig. 1**,

$$AB + CD = AD + BC \qquad (1)$$