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Effect of Particle Properties on Fluidized Powder Conveying in a Horizontal Channel

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Abstract

This study experimentally investigated the dense phase pneumatic conveying in a horizontal rectangular channel using the fluidizing air. The powder used the glass beads belongs to Geldart B particle, where the mean particle diameter is 127μm, the particle density is 2623kg/m^3 and the minimum fluidizing velocity is 12.3mm/s. The experimental device consists of a powder discharge vessel, a horizontal rectangular channel at the side of vessel and the air supply section at the bottom of the vessel and the horizontal channel. The powder was fluidized by air through the porous membrane of the air supply section at the bottom of the vessel and the horizontal channel. Then, this system can be conveyed the fluidized powder. As the result, we confirmed the requirement that the fluidizing air to the bottom of the powder discharge vessel was required to the powder conveying of this system, and that the fluidizing velocity at the bottom of the horizontal channel was larger than that of the minimum fluidizing velocity. This result means that the fluidizing velocity at the bottom of the vessel and the horizontal channel is important to obtain the stable powder conveying. The mass flow rate and solid loading ratio were estimated by the measured data of the mass of transported powder. In addition, these results were compared with the conveying characteristic of the glass beads of 53μm belongs to Geldart A particle. Then, the mass flow rate of Geldart A particle was higher than that of Geldart B particle. The solid loading ratio of the Geldart A particle was also greatly large to that of Geldart B particle. Therefore, we considered that the high conveying efficiency to Geldart A particle was obtained, when the dimensionless fluidizing velocities at the bottom of the powder discharge vessel and the horizontal channel were same condition.

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Keywords: Powder conveying, Fluidization, Minimum Fluidizing velocity, Particle diameter, Mass flow rate, Solid loading ratio ;

1. Introduction

Pneumatic conveying system is widely used in various powder handling processes such as food, pharmaceutical and chemical engineering industries. There are disadvantages in this system such as high power consumption and breakage of particle. Dense phase pneumatic conveying in a pipeline is applied to avoid these disadvantages [1]. Therefore, many researchers were investigated the flow characteristics on this conveying system [2-5]. From these studies, we can understand that the minimum transport boundary and the flow pattern are important to operate the dense phase pneumatic conveying in a horizontal pipeline. On the other hand, there are disadvantages in the dense phase pneumatic conveying such as the generation of pipe blockages, the intermittent powder conveying and the increased in power consumption depends on the influence of the pipe wall compared with the mechanical conveying [1, 6]. Therefore, it is necessary to investigate how to reduce these disadvantages.

Using fluidized gravity conveyors known as air slides is one method for dense phase pneumatic conveying. This type of conveyor consists of an inclined channel in which powder flows under the influence of gravity. Powders such as Geldart A and B

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particles [7] are fluidized in the channel for powder conveying by air flow through a suitable distributor [8]. In this system, the particle-particle force and the frictional force between the particle and the channel surface can be reduced by the fluidizing air [9], giving the fluidized gravity conveyor the advantages of low solid velocity with little attrition loss, high mass flow rate and low specific power consumption [8]. In addition, this conveyor can be avoided from disadvantages such as pipe blockage and intermittent conveying. Therefore, the flow characteristics of fluidized gravity conveyors have also been examined [4, 10-15].

We noticed from these earlier studies [4, 11-15] that the powder was discharged from a hopper on the upside of a channel by the free fall, and was transported by applying air to the channel. However, if the discharge of the powder from a hopper by the free fall is not sufficient, the use of this conveying system will be limited. Moreover, we could not understand the conveying characteristics of fluidized powder in detail when the discharge of the powder from a hopper by the free fall was not used. Therefore, we experimentally examined the conveying characteristics of fluidized powder in an enclosed horizontal rectangular channel without the discharge of the powder from a hopper by the free fall [16-17]. This conveyor is consists of a powder discharge vessel and a horizontal rectangular channel placed at the side of the vessel. In the previous study, we used the glass beads belong to Geldart A particles. As the result, we found that the fluidized powder could be conveyed smoothly when air was supplied to the bottom of the vessel and the air velocity at the bottom of the horizontal channel exceeded the minimum fluidizing velocity. Further, the characteristic of the flow pattern in the discharge vessel and the horizontal channel was obtained [16]. In addition, we indicated that the effect of fluidizing velocity at the bottom of the powder discharge vessel and the horizontal channel on the limitation of powder conveying in this system, and that the high dense powder conveying was feasible in this system [17]. However, the effect of the particle properties to the fluidized powder conveying in this system could not be understood.

In this study, we experimentally investigated the fluidized powder conveying in a horizontal rectangular channel using glass beads belong to Geldart B particle. We discussed the conveying characteristics such as the mass of transported powder, the mass flow rate and the solid loading ratio when the fluidizing velocities at the bottom of the powder discharge vessel and the horizontal channel were varied against the minimum fluidizing velocity. Further, we also examined the conveying characteristics on the different particle.

Nomenclature

d_p	Particle diameter (m)
G_a	Total mass flow rate of air (kg/s)
G_{smax}	Maximum mass flow rate of powder (kg/s)
M_p	Mass of transported powder (kg)
M_{pi}	Initial mass of powder (kg)
m_{max}	Maximum solid loading ratio (-)
Q_h	Flow rate of air at the bottom of powder discharge vessel (m^3/s)
Q_t	Flow rate of air at the bottom of horizontal channel (m^3/s)
t	Elapsed time (s)
u_h	Fluidizing velocity at the bottom of powder discharge vessel (mm/s)
u_{mf}	Minimum fluidizing velocity (mm/s)
u_t	Fluidizing velocity at the bottom of horizontal channel (mm/s)
ρ_a	Air density (kg/m^3)

2. Experiment

Fig.1 shows a schematic diagram of experimental apparatus. The powder conveying system is that consist of an opened powder discharge vessel, an enclosed horizontal rectangular channel and a receiving tank. The supply section of the air was placed at the bottom of the powder discharge vessel and the horizontal channel. An opened powder discharge vessel was used to the acrylic pipe where the inside diameter is 241mm and the height is 1000mm. A horizontal rectangular channel which has the width and height of 30mm and the conveying length of 1000mm was made from the acrylic plate. The porous membrane having the thickness of 6mm was arranged in the bottom of the vessel and the horizontal channel to give a uniform upward flow of air. As the supply of fluidizing air, the flow rate of air was adjusted by the mass flow controller.

The mass of discharged powder from the exit of horizontal channel was measured by a load cell at the bottom of receiving tank. Also, we measured the change of the total mass of experimental apparatus and the powder by three load cells at the bottom of the vessel and the horizontal channel. For the discussion of this study, we used the data measured by the three load cells to represent the mass of the transported powder. The air pressures at the bottom of the vessel and the horizontal channel were measured by the pressure sensor. The change of bed height of powder in a vessel during the powder conveying was recorded by a laser displacement sensor. Output signals from the load cells, the pressure sensors, a laser displacement sensor and the mass flow controllers were stored every 50ms, and the measuring time for each experiment was 180 seconds.

Table 1 shows the particle properties of two glass beads where d_p is the mean particle diameter, ρ_p is the particle density and u_{mf} is the minimum fluidizing velocity. The glass beads belong to Geldart B particle [7] was used in this study. Also, in the previous study, we investigated to the powder conveying of Geldart A particle using fluidizing air [16-17]. From this table, we confirmed that the mean particle diameter and the minimum fluidizing velocity were different to the both particles. Therefore, we could be inspected the effect of the particle properties to the powder conveying using the fluidization.

Table 2 shows the experimental conditions in our study where M_{pi} is the initial value of mass of powder in a powder discharge vessel, Q_h and Q_t are the flow rate of air at the bottom of the powder discharge vessel and the horizontal channel. Further, u_h/u_{mf} and u_t/u_{mf} are the dimensionless air velocity at the bottom of the vessel and the horizontal channel where u_h and u_t were calculated from the flow rate of air and the cross sectional area, respectively.

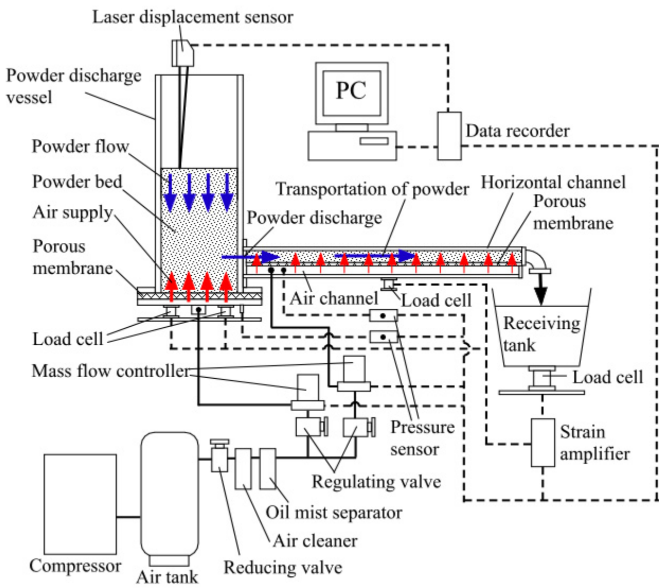

Fig. 1. Experimental apparatus.

Table 1. Particle properties.

Particle	Geldart classification	d_p (μm)	ρ_p (kg/m^3)	u_{mf}(mm/s)
Glass beads A	A	53	2523	4.3
Glass beads B	B	127	2623	12.7

Table 2. Experimental conditions.

Particle	M_{pi} (kg)	Q_h (m^3/s)	Q_t (m^3/s)	u_h / u_{mf}	u_t / u_{mf}
Glass beads A	30	$(0\text{~}3)\times10^{-4}$	$(1.167\text{~}8.333)\times10^{-4}$	0 ~ 1.519	0.898 ~ 6.417
Glass beads B	30	$(0\text{~}8.52)\times10^{-4}$	$(3.313\text{~}14.2)\times10^{-4}$	0 ~ 1.519	0.898 ~ 3.85

3. Results and discussions

Fig.2 shows the time histories of mass of transported powder when the fluidizing air was supplied to the bottom of the powder discharge vessel and the horizontal channel. The conveyed powder was the glass beads B, M_p is the mass of transported powder and t is the elapsed time. As the experimental condition of this figure, the dimensionless fluidizing velocity at the bottom of the vessel was kept constant, u_h/u_{mf}=1.0, and the dimensionless fluidizing velocity to the horizontal channel u_t/u_{mf} was changed from 0.898 to 3.85. We found that the powder could not be conveyed when the fluidizing velocity at the bottom of the horizontal channel was lower than the minimum fluidizing velocity. Also, the powder conveying in this condition was not enough that the fluidizing velocity at the bottom of the horizontal channel was close to the minimum fluidizing velocity. On the other hand, we confirmed that the mass of transported powder increased rapidly when the fluidizing velocity at the bottom of the horizontal channel surpassed the minimum fluidizing velocity. In addition, we noticed that the profile of the transported powder against the elapsed time was almost the same as the dimensionless fluidizing velocity at the bottom of the horizontal channel exceeded 2.567. These results were obtained to other experimental conditions in this study and the previous study using the glass beads A of 53μm [16-17].

Fig.3 shows the result of the judgement on the state of the powder conveying of the glass beads B where the fluidizing velocities at the bottom of the powder discharge vessel and the horizontal channel were changed. We defined that the judgment of the powder conveying created the figure of the time histories of the mass of the transported powder as shown in Fig.2, and it classified into the following four powder flow. When the powder could not be conveyed, it plotted as no conveying in Fig.3. This powder flow appeared when the fluidizing air at the bottom of the powder discharge vessel was not supplied. Also, the mass of the transported powder increased linearly with the increase in the elapsed time. However, the amount of the mass of the transported powder was smaller than that of the initial mass of the powder in the vessel. These profiles appeared that u_t/u_{mf} was changed from 0.898 to 1.283 in Fig.2 and that seemed to the almost linear change. This flow expressed with the linear conveying in Fig.3. Further, the intermediate powder conveying showed into Fig.3. This flow mode defined that the mass of the transported powder was larger than that of the linear conveying. In addition, the stable conveying of the fluidized powder was also represented in Fig.3. This flow region could be confirmed when u_t/u_{mf} exceeded 2.567 in Fig.2. These profiles of the mass of the powder against the elapsed time were almost the identical profiles. From the result in Fig.3, we comprehended the requirement that the fluidizing air to the bottom of the vessel was required to the powder conveying of this system, and that the fluidizing velocity at the bottom of the horizontal channel was larger than that of the minimum fluidizing velocity. These results were also obtained the previous study using Geldart A particle [17].

Fig.4 shows the relationship between the maximum mass flow rate of the powder G_{smax} and the dimensionless fluidizing velocities at the bottom of the powder discharge vessel and the horizontal channel where the conveying powder was the glass beads B of 127μm. The mass flow rate of the powder represented the gradient of the mass of the powder against the elapsed time as shown in Fig.2. The gradient of the mass of the transported powder in Fig.2 varied the increase in elapsed time. Therefore, it was calculated to the interval of 2.5 seconds from the beginning of powder conveying on each experiment data. The data analysis of the mass flow rate of powder in this study performed between 0 and 90 seconds of elapsed time. Fig.4 plotted the maximum value of the analyzed mass flow rate on each experimental condition. The maximum mass flow rate of the glass beads B increased rapidly when the fluidizing velocity at the bottom of the horizontal channel exceeded the minimum fluidizing velocity. Further, the mass flow rate increased with increasing the fluidizing velocity at the bottom of the horizontal channel. Also, the mass flow rate has taken the constant value, or it decreased gradually with increasing the fluidizing velocity at the bottom of the horizontal channel. In addition, the maximum mass flow rate of powder increased with increasing the fluidizing velocity at the bottom of the powder discharge vessel. When the fluidizing velocity at the bottom of the vessel exceeded the minimum fluidizing velocity, the change of the maximum mass flow rate against the fluidizing velocity at the bottom of the horizontal channel was almost similar.

Fig.5 shows the maximum solid loading ratio against the dimensionless fluidizing velocity at the bottom of the horizontal channel where the dimensionless fluidizing velocity at the bottom of the powder discharge vessel was also changed. The maximum solid loading ratio m_{max} was calculated by the following definition.

$$m_{\max} = \frac{G_{s\max}}{G_a} = \frac{G_{s\max}}{\rho_a\left(Q_h + Q_t\right)} \tag{1}$$

where G_a is the total mass flow rate of the supplied air on each experimental condition, ρ_a is the density of air, Q_h and Q_t are the flow rate of air to the powder discharge vessel and the horizontal channel, respectively. As the result in Fig.5, the maximum solid loading ratio increased rapidly with increasing the fluidizing velocity at the horizontal channel, and it reached the maximum value. Also, the maximum solid loading ratio decreased suddenly with the increase in the fluidizing velocity at the bottom of the horizontal channel. In addition, an increase in the maximum solid loading ratio increased with increasing the fluidizing velocity at the bottom of the vessel. Further, the profile of the maximum solid loading ratio was almost same as well as the result of the maximum mass flow rate of powder.

Fig.6 shows the maximum mass flow rate of the different particles where the dimensionless fluidizing velocities at the bottom of the vessel and the horizontal channel were changed. In this figure, the maximum mass flow rate of both powder increased with increasing the fluidizing velocity at the bottom of the horizontal channel. Further, the maximum mass flow rate against the increase in the fluidizing velocity at the bottom of the horizontal channel has taken the constant value, or it decreased gradually with increasing the fluidizing velocity at the bottom of horizontal channel. Further, we confirmed that the maximum mass flow rate of the glass beads A of 53μm was larger than that of the glass beads B of 127μm.

Fig.7 shows the maximum solid loading ratio of the different particles against the change of the fluidizing velocities at the bottom of the vessel and the horizontal channel. As the result in Fig.7, the maximum solid loading ratio of the glass beads A of 53μm was greatly high to that of the glass beads of 127μm. Therefore, we found that the high transport efficiency to the small particle was obtained, when the dimensionless fluidizing velocities at the bottom of the vessel and the horizontal channel were same condition.

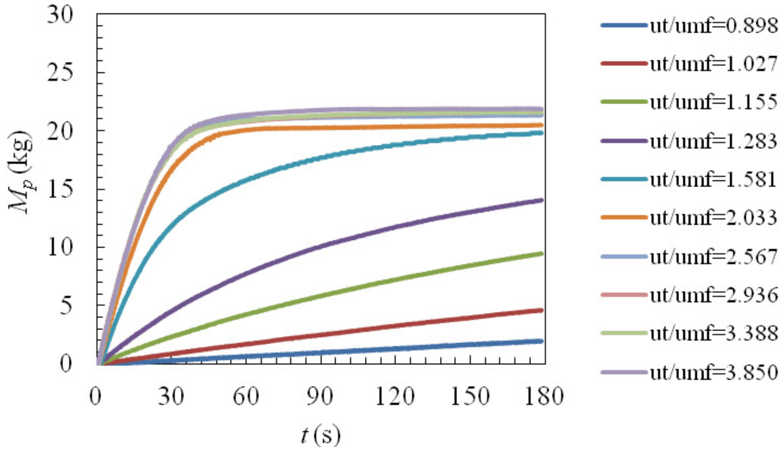

Fig. 2. Time histories of the mass of transported powder where the glass beads B of 127μm and u_h/u_{mf}=1.0.

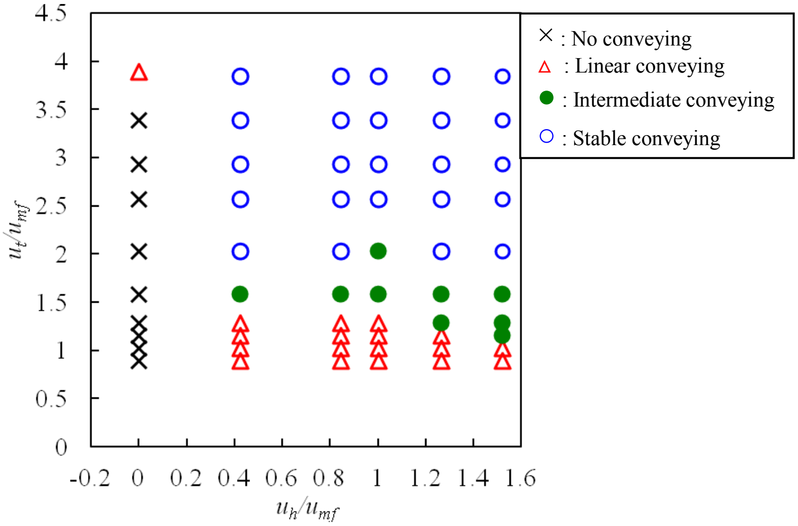

Fig. 3. The state of powder conveying of the glass beads B of 127μm with the fluidizing velocity.

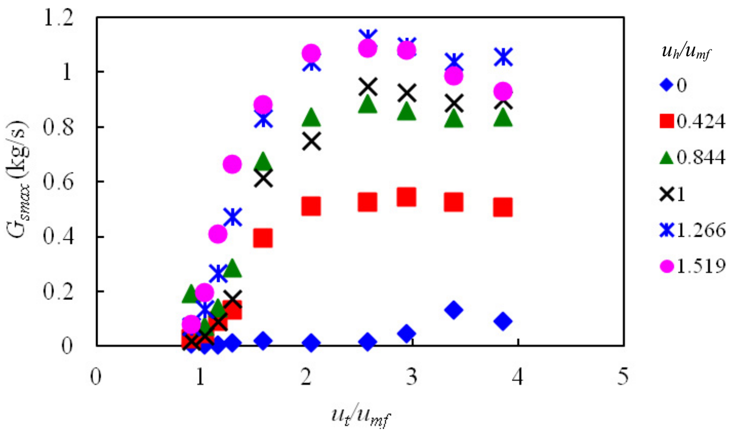

Fig. 4. Relationship between the mass flow rate of the glass beads B of 127μm and the fluidizing velocity.

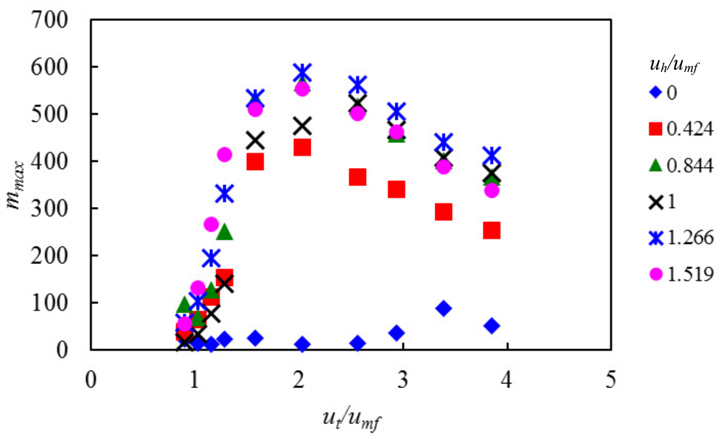

Fig. 5. Relationship between the solid loading ratio of the glass beads B of 127μm and the fluidizing velocity.

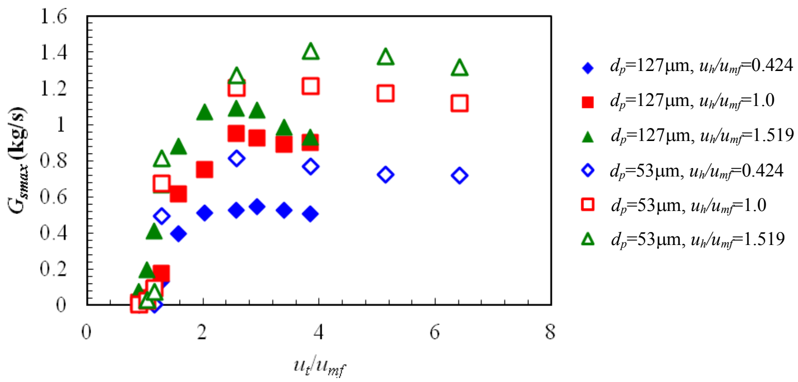

Fig. 6. Comparison of the maximum mass flow rate of the different particles.

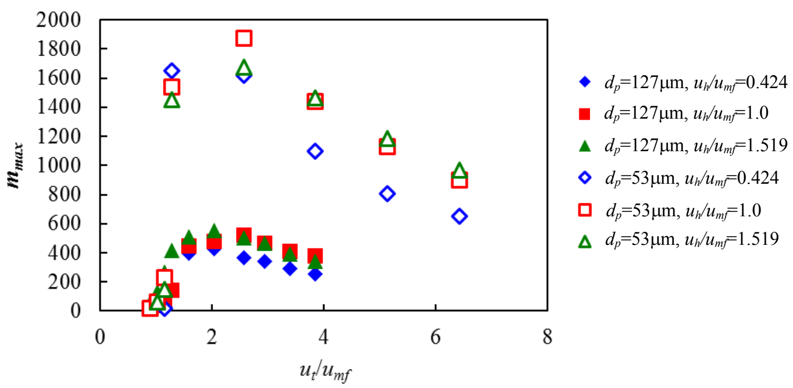

Fig. 7. Comparison of the solid loading ratio with the different particles.

4. Conclusion

The fluidized powder conveying of two glass beads belong to A and B particle in the Geldart classification has been experimentally studied. In addition, the conveying characteristics of the different particles were compared when the fluidizing velocities at the bottom of the powder discharge vessel and the horizontal channel were varied. We obtained the following results to the characteristics of powder conveying.

(1) We comprehended the requirement that the fluidizing air to the bottom of the powder discharge vessel was required to the powder conveying of this system, and that the fluidizing velocity at the bottom of the horizontal channel was larger than that

of the minimum fluidizing velocity. Therefore, the air supply to the bottom of the vessel and the horizontal channel was significant greatly in this system.

(2) The mass flow rate and solid loading ratio of Geldart A particle were larger than that of Geldart B particle. Therefore, we considered that the high transport efficiency to the small particle was obtained, when the dimensionless fluidizing velocities at the bottom of the powder discharge vessel and the horizontal channel were same condition.

References

[1] K. Konrad, Dense-phase pneumatic conveying: A Review, Powder Technology, 49 (1986) 1-35.
[2] P. W. Wypych and J. Yi, Minimum transport boundary for horizontal dense-phase pneumatic conveying of granular materials, Powder Technology, 129 (2003) 111-121.
[3] P. Pan, Material properties and flow modes in pneumatic conveying, Powder Technology, 104 (1999) 157-163.
[4] Y. Tomita, V. K. Agrawal, H. Asou and K. Funatsu, Low-velocity pneumatic conveying in horizontal pipe for coarse particles and fine powders, Particuology, 6 (2008) 316-321.
[5] Y. Tomita and H. Asou, Low-velocity pneumatic conveying of coarse particles in a horizontal pipe, Powder Technology, 196 (2009) 14-21.
[6] K. Kofu, M. Ochi, M. Takei and Y. Hirai, Pressure drop reduction by applying ultrasonic for plug transportation of granular particles, J. Soc. Powder Technol., Japan, 46 (2009) 858-864.
[7] D. Geldart, Type of gas fluidization, Powder Technology, 7 (1973) 285-292.
[8] G. E. Klinzing, R. D. Marcus, F. Rizk and L. S. Leung, Pneumatic Conveying of Solids – A Theoretical and Practical Approach, second ed., Chapman and Hall, 1997. pp.340-347.
[9] C. R. Woodcock and J. S. Mason, Bulk Solid Handling – An Introduction to the Practice and Technology, Leonard Hill, 1987. pp.456-477.
[10] M. Ishida, H. Hatano and T. Shirai, The flow of solid particles in an aerated inclined channel, Powder Technology, 27 (1980) 7-12.
[11] D. Latkovic and E. K. Levy, The flow characteristics of fluidized magnetite powder in an inclined open channel, Powder Technology, 67 (1991) 207-216.
[12] M. M. Rao and S. Tharumarajan, Experimental investigations on fluidized gravity conveying, Bulk Solids Handling, 6-1 (1986) 99-103.
[13] S. K. Gupta, V. K. Agrawal, S. N. Singh, V. Seshadri and David Mills, An experimental investigation on a fluidized motion conveying system, Powder Technology, 167 (2006) 72-84.
[14]S. K. Gupta, V. K. Agrawal, S. N. Singh, V. Seshadri and David Mills, Parameters affecting fluidized motion conveying of fly ash, Particulate Science and Technology, 26 (2009) 469-487.
[15] S. K. Gupta, V. K. Agrawal and David Mills, A model for fluidized motion conveyor transporting fly ash, Experimental Thermal and Fluid Science, 34-8 (2010) 1042-1048.
[16] K. Ogata, T. Furukawa and Y. Yamamoto, Fluidized powder conveying in a horizontal rectangular channel using fluidizing air, Advanced Powder Technology, 23-6 (2012) 761-770.
[17] K. Ogata, T. Furukawa and Y. Yamamoto, Influence of fluidizing velocity of fluidized powder conveying in a horizontal rectangular channel, Proceedings of ASME-JSME-KSME Joint Fluids Engineering Conference 2011 on USB, AJK2011-12012, (2011) 1-7.