Characteristics of Constant Value on the Specific Pressure Drop in Dilute Phase Pneumatic Conveying for Different Plastic Particles

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Abstract

The present study purposes the characteristics for the constant value of pressure drop (K_t) in the dilute phase pneumatic conveying that leads to total system-pressure drop in straight horizontal steel pipe. The solid phase were polyethylene recycled (Recycled PE), high density polyethylene (HDPE), and low density polyethylene (LDPE). The solid phases were at different density, sphericity, and shape. Moreover, the characteristics of specific pressure drops of the flows were investigated for various Reynolds number (88,912 to 145,732), Froude number (21.41 to 39.01), and sphericity. The specific pressure drop of the three type plastic particles also increased with the solids loading ratio, Reynolds number, and Froude number. However, the K_t value was found to be quite constant for a certain type of plastic particle. However, this K_t value was found to be affected by the sphericity of the moving particles.

***Keywords*:** Pneumatic conveying; Dilute phase; Pressure gradient; Plastic particles; Horizontal pipeline

1. Introduction

The effect of the variation of materials properties on the pressure drop of the pneumatic conveying are needed to be well understood. This understanding leads to the improvement of design for pipe size and air blower selection. Previous works [1-4] found that the system pressure drop varies directly with the air velocity and particle feeding rate. Furthermore, the pressures drop also affected by mean diameter, shape, particle distribution, cohesion of particle density, and even the collision pattern [5]. Some of the works [6] also studied the effect of surface hardness where two types of material e.g. polyolefin and polystyrene were experimentally conducted. This present study aiming at the effects of such those physical properties on the system pressure drop and trying to recommend a constant value related to the prediction of the system pressure drop.

Previous works [7-8] revealed that the system pressure drop (ΔP_t) comprises of the pressure drop due to the air flow (ΔP_a) and the pressure drop concerning the presence of transport particle (ΔP_s) as show in Equation (1) [7-10].

$$\Delta P_t = \Delta P_a + \Delta P_s \tag{1}$$

where (ΔP_a) can be obtained by using Darcy-Weisbach relation, as shown in Equation (2).

$$\Delta P_a = \frac{f_a V_a^2 \Delta L}{2D} \tag{2}$$

Equation (3) which based on [11] gives the relationship between ΔP_a and ΔP_s . This ΔP_s represents the effects of wall friction between particles and inner wall surface of the pipe, the collision among the particles themselves, and the drag force while the particles flow in the air,

$$\Delta P_s = \Delta P_a K_t \mu \tag{3}$$

where μ is the particle loading ratio to air. The K_t value is the "specific pressure drop constant", and the system pressure drop can then be obtained from the following equation .

$$\Delta P_t = \Delta P_a \left(1 + K_t \mu\right) \tag{4}$$

In this present study, the experimental values of K_t were obtained by Equation (5).

$$\frac{\Delta P_t}{\Delta P_a} - 1 = K_t \mu \quad (5)$$

Therefore, the objective of this study was to determine the characteristic of constant value of the specific total pressure drop and to determine the minimum velocities to convey the materials in pneumatic conveying plastic particles with different density, shape, and average mean diameter in a horizontal straight line.

2. Experiment

2.1. The rig and equipments

The experiment aimed to determine the constant value of total specific pressure drop and characteristics of dilute phase pneumatic conveying of plastic particles in a horizontal straight line. The pneumatic conveying system is shown in Fig. 1 and consists of blower (1), air velocity measuring device (2), pipe line system (3), transparent section (4), pressure drop measurement tapping (5), cyclone (6), hopper (7), and rotary feeder (8). The pipe line system is both the lower horizontal and upper horizontal lines, connected with a vertical pipe and has an equivalent inside diameter was 0.079 m. The pressure drop due to air and total pressure gradients were measured at upper horizontal pipe section (8.57 m in length) by U-tube water manometers (ASHRAE standard 41.3-1989). The average velocity of air was determined by the calibrated pitot tube at the point before the rotary feeder (2). The uncertainty of average air velocity was determined and comparison made between experiments and theoretical values for air pressure drop in a straight line of different inside diameters of PVC by using Fanning's equation. [12-13].

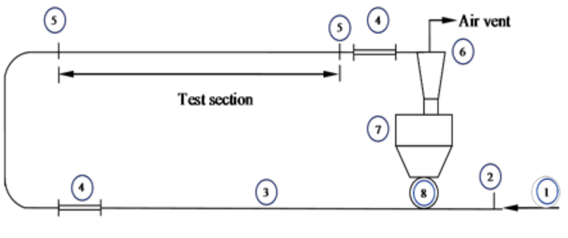

Fig. 1 Schematic diagram of experimental apparatus

The air velocity and solid mass flow rate were adjusted by two independent inverters to control the frequency of blower over 36 – 50 Hz and of rotary feeder over 32 – 50 Hz. During each run, the air velocity was constant but the solid loading ratio was increased until the plastic particles blocked the flow. The pressure drop, air velocity and solid mass flow rate were collected for every data set of solid loading ratio at the steady flow condition.

2.2. Description of test materials

The physical properties of plastic particles were determined the M.Guner method [14] as shown in Table 1. The polyethylene had a cylindrical shape with average length (L), width (W), and thickness (T) of 3.97 mm, 3.07 mm, and 3.07 mm, respectively. The high density polyethylene had a cylindrical shape with average length (L), width, (W), and thickness (T) of 3.72 mm, 2.55 mm, and 2.55 mm, respectively. The average diameter (width), the length, and the thickness of the low density polyethylene with them spherical shape were 4.57 mm, 2.6 mm, and 2.78 mm, respectively. The true density and the bulk density were determined by using the toluene displacement method [14-17].

Table 1 Means and standard deviation of physical properties of some plastic particles

Properties		Plastics particle		
		LDPE	HDPE	Recycle PE
Arithmetic mean diameter(mm)		3.44 ± 0.19	2.94 ± 0.17	3.37 ± 0.18
Geometric mean diameter (mm)		3.34 ± 0.16	2.89 ± 0.14	3.33 ± 0.14
Sphericity(%)		73.21 ± 0.03	75.18 ± 0.04	84.42 ± 0.04
Bulk density(kg/m^3)		493.72 ± 5.49	625.82 ± 3.64	575.22 ± 2.00
True density(kg/m^3)		904.50 ± 3.66	938.25 ± 5.85	915.66 ± 2.56
Porosity(%)		45.41 ± 0.60	33.29 ± 0.12	37.17 ± 0.14
Inlet air velocity(m/s)	Max.	32.43 ± 0.1	33.04 ± 0.46	33.42 ± 0.2
	Min.	22.87 ± 0.1	24.51 ± 0.81	14.21 ± 1.07
Solids mass flow rate (kg/s)		0.31 ± 0.01 - 0.52 ± 0.02	0.33 ± 0.0061 - 0.57 ± 0.023	0.36 ± 0.015 - 0.59 ± 0.016
Solids loading ratios		1.67 ± 0.063 - 4.28 ± 0.088	1.67 ± 0.19 - 4.44 ± 0.36	1.80 ± 0.086 - 6.61 ± 0.17

3. Results and Discussion

Due to the fact that the minimum velocity of each test run could be notified by the observation section, it was observed that the ranges of minimum velocity of recycled PE, HDPE, and LDPE were 14.21-33.42 m/s, 24.51 – 33.04 m/s, and 22.87 - 32.43 m/s, respectively. The lowest range of minimum velocity associated with recycled which occupied lowest mean diameter and lowest true density as also found by [2, 3, 6, 12, 14, 18-20].

Fig. 2 to 4 reveal the linear-like relationship between specific pressure drop $(\Delta P_t / \Delta P_a)$ to solid loading ratio (μ) of each tested material. Fig. 5 shows the pattern of $(\Delta P_t / \Delta P_a)$ versus solid loading ratio which can be seen that the K_t values varies significantly with type of particle. It can be seen that the K_t values are 0.356, 0.299, and 0.256 for recycled PE, HDPE, and LDPE, respectively. Fig. 6 shows the precision of K_t value for all present test condition (229 data points) with standard residual 95%. It was found that K_t is quite constant when both Reynolds number and Froude number were varied. Fig. 8 to

15 reveal the K_t values of each tested material at different solid loading ratio when Re and Fr were varied. Fig. 16 reveals the effect of sphericity of the particle. It can be seen that the higher sphericity (in this case, Recycled PE) yields higher K_t value.

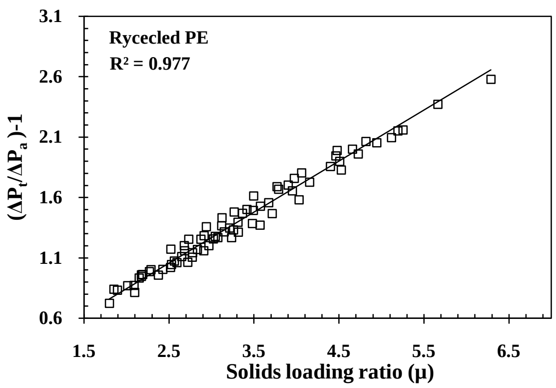

Fig. 2 Specific pressure drop with increasing solids loading ratios of recycled polyethylene in average air velocity range 14.21 <V_a<33.42 m/s.

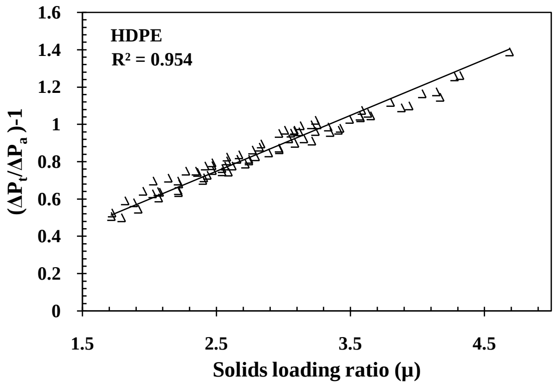

Fig. 3 Specific pressure drop with increasing solids loading ratios of high density polyethylene in average air velocity range 24.51< V_a<33.04 m/s .

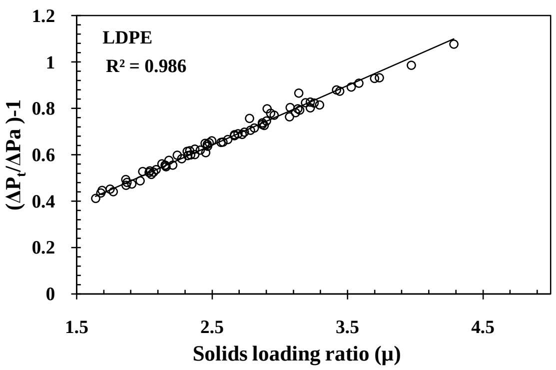

Fig. 4 Specific pressure drop with different solids loading ratios of low density polyethylene in average air velocity range 22.87 <V_a< 32.43 m/s.

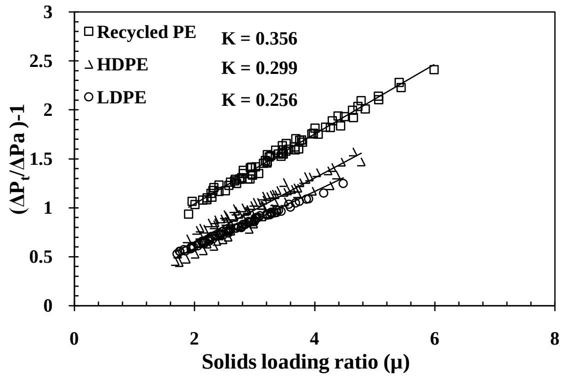

Fig. 5 Specific pressure drop with different solids loading ratios of high density polyethylene, low density polyethylene, and recycled polyethylene.

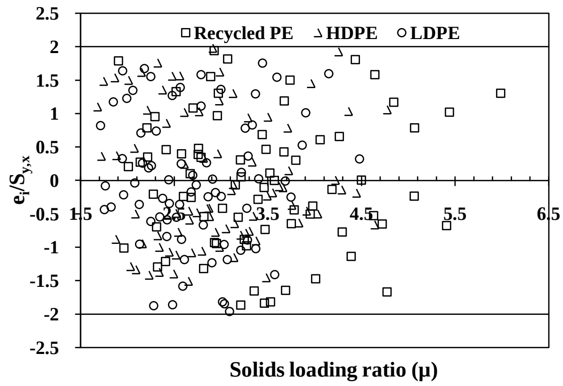

Fig. 6 Characteristics of specific pressure drop constant with increasing solids loading ratio of Recycled PE, HDPE and LDPE (confidence level 95%)

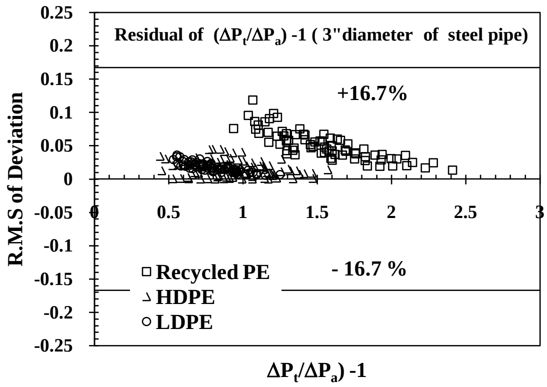

Fig. 7 R.M.S of deviation between present experimental data and A.T. Agarwal's prediction [11].

Fig.7 shows the comparison between experimental data and well-known prediction by A.T. Agarwal method [11], The results reveal good agreement within 16.7 % of the R.M.S.

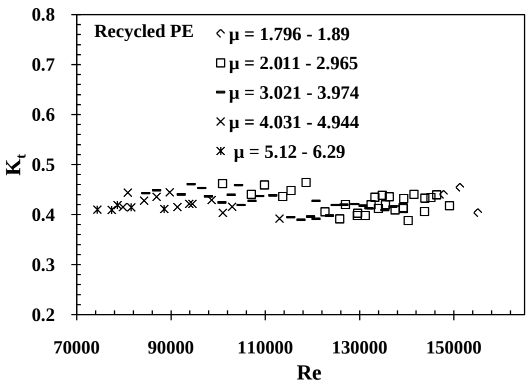

Fig. 8 Characteristics of specific pressure drop constant and Reynolds number with different solids loading ratio of Recycled PE.

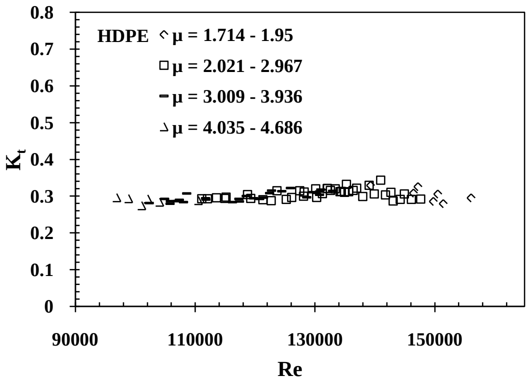

Fig. 9 Characteristics of specific pressure drop constant value and Reynolds number with different solids loading ratio of HDPE

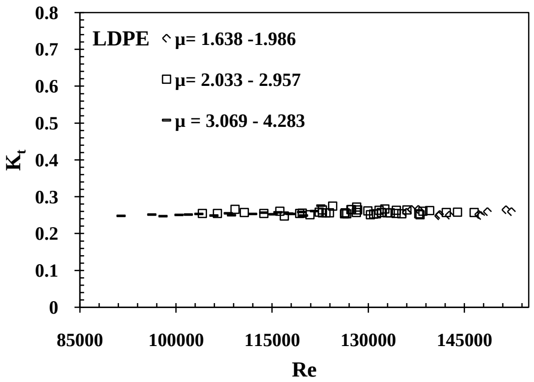

Fig. 10 Characteristics of specific pressure drop constant and Reynolds number with different solids loading ratio of LDPE

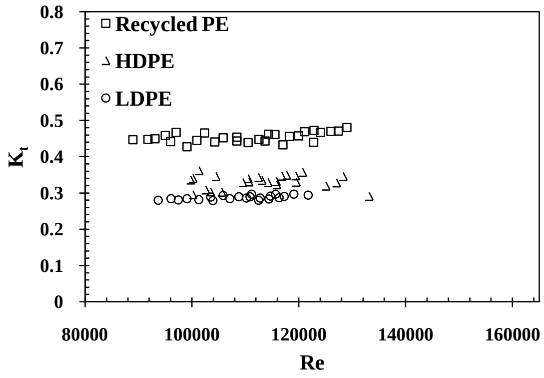

Fig. 11 Comparison of specific pressure drop constant between different plastic particles with similar solids loading ratio (μ = 3.013 - 3.98)

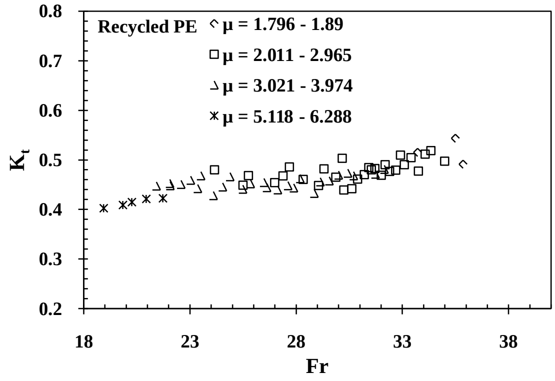

Fig. 12 Characteristics of specific pressure drop constant and Froude number with different solids loading ratio of Recycled PE.

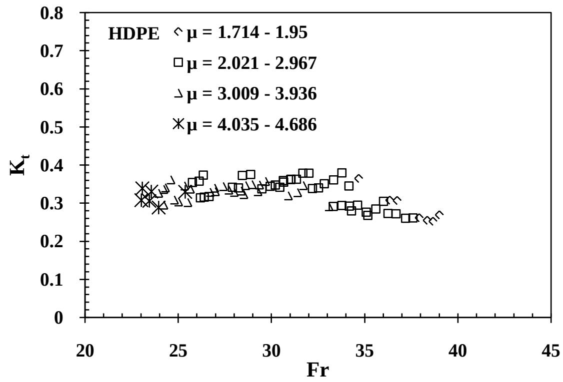

Fig. 13 Characteristics of specific pressure drop constant and Froude number with different solids loading ratio of HDPE.

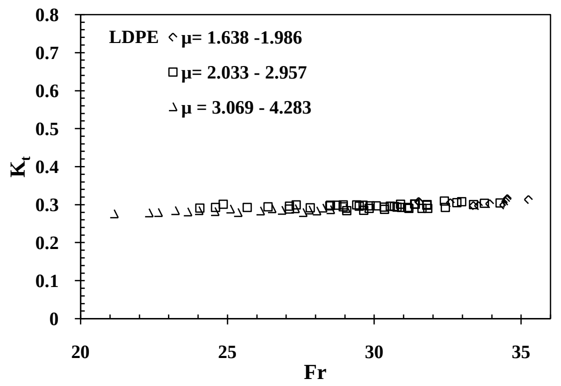

Fig. 14 Characteristics of specific pressure drop constant and Froude number with different solids loading ratio of LDPE

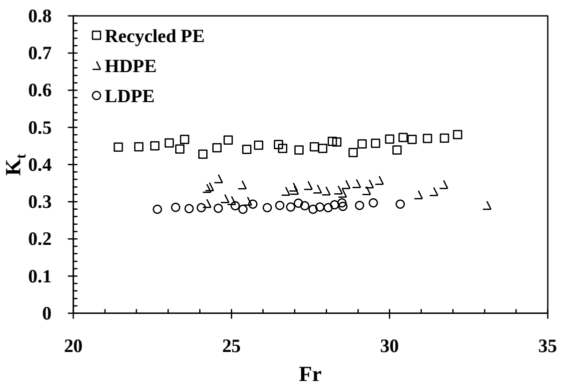

Fig. 15 Comparison of characteristics of specific pressure drop constant and Froude number with different plastic particles with similar mass fraction (μ = 3.013 – 3.98 kg solid/kg air)

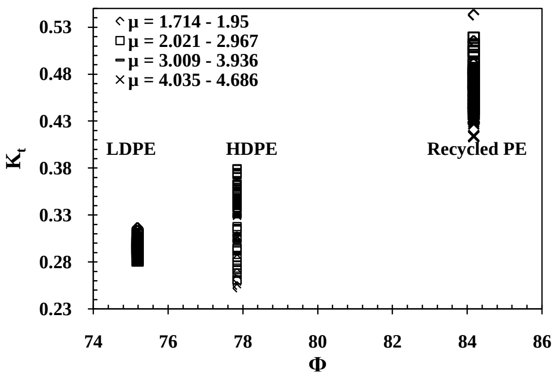

Fig. 16 Characteristics of specific pressure drop constant vs. sphericity for LDPE, HDPE and recycled PE with similar mass fraction

4. Conclusions

According to the present experiment study, there are some significant findings for system pressure drop of pneumatic conveying as follows.

1. the systems pressure drop may be calculated by the use of Equation (1)

2. the K_t value quite depends upon the type of particle or grain. In the present study the K_t values are 0.356, 0.299, and 0.256 for recycled PE, HDPE, and LDPE, respectively.

3. the K_t value also depends upon the particle sphericity (ϕ). The greater ϕ, the higher K_t value.

Since the present study was focused on 3-in-diameter steel pipe, it is fair to say that the size and type of the pipe must be further investigated on this K_t value in order to find the in-depth behavior of such specific pressure drop constant.

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6. Nomenclature

ΔP_t	Total pressure drop (Pa)
ΔP_a	Pressure drop due to gas flow (Pa)
ΔP_s	Pressure drop due to the particle friction and impact (Pa)
f_a	Air friction factor
Re	Reynolds number
Fr	Froude number
K_t	Specific Pressure drop constant
ρ_a	Gas density (kg/m^3)
$\dot{m}_s$	Solids mass flow rate (kg/s)
V_a	Average air velocity (m/s)
ΔL	Distance between pressure taps (m)
D	Pipe diameter (m)
K	Constant pressure drop of solid
μ	Solids loading ratios
Φ	Sphericity

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