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PRESSURE DROP IN PACKED BEDS OF SPHERICAL PARTICLES AT AMBIENT AND ELEVATED AIR TEMPERATURES

Article Highlights

- Particle friction factor for air flow through packed bed of particles was investigated
- Experiments were performed at ambient and at elevated temperatures
- The obtained results were correlated using a number of literature correlations
- Ergun's equation best correlated the experimental data

Abstract

The aim of this work was the experimental investigation of the particle friction factor for air flow through a packed bed of particles at ambient and elevated temperatures. The experiments were performed by measuring the pressure drop across the packed bed, heated to the desired temperature by hot air. Glass spherical particles of seven different diameters were used. The temperature range of the air flowing through the packed bed was from 20 to 350 °C and the bed voidages were from 0.3574 to 0.4303. The obtained results were correlated using a number of available literature correlations. The overall best fit of all of the experimental data was obtained using the Ergun equation, with mean absolute deviation of 10.90%. Ergun's equation gave somewhat better results in correlating the data at ambient temperature with mean absolute deviation of 9.77%, while correlation of the data at elevated temperatures gave mean absolute deviation of 12.38%. The vast majority of the correlations used gave better results when applied to ambient temperature data than to the data at elevated temperatures. Based on the results obtained, the Ergun equation is proposed for friction factor calculation both at ambient and at elevated temperatures.

Keywords: pressure drop, packed bed, elevated temperature.

Packed beds of particles are widely used in the process industry. The range of applications includes filtration, catalytic reactions, heat transfer, gas scrubbing, grain drying and many others. In these applications, both spherical and non-spherical particles are used resulting in different bed characteristics, including different bed voidages. In order to be able to adequately design the mentioned processes, it is important to be able to accurately predict parameters of the system. One of the most important parameters to be assessed is the pressure drop of the fluid flowing through the packed bed. Due to the complex nature of the fluid flow through the bed, many of the equations used are empirical in nature. The flow of the fluid through the pores of the system was modeled by analogy with the tube fluid flow, taking that the channels through which the fluid flows are approximately of the diameter of the particles constituting the bed. Empirical constants were then added in order to adjust the obtained equations to the experimental results. The most important pressure drop correlations and the range of their applicability are discussed in the following section.

Despite the great number of studies dealing with the pressure drop across packed beds of particles [1--13], to our knowledge there are no investigations of the packed bed pressure drop at elevated temperatures. In their study, Luckos *et al.* [3] found that the values of the pressure drop in a commercial gasifier

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calculated according to the Ergun equation [1] are not satisfactory. According to the authors, one of the reasons for this is the variation of temperature, composition and pressure of the gases flowing through the packed bed in the gasification process.

The aim of this work was the experimental investigation of the influence of the temperature of the gas on the packed bed pressure drop and the applicability of the literature correlations at elevated temperatures. To achieve this, experimental investigation of the particle friction factor, f_p, for gas flow through packed beds of spherical glass particles at ambient and elevated temperatures was conducted. The experiments were performed by measuring the pressure drop across the packed bed, previously heated to desired temperature by the hot air flowing through it. The temperature range of the experiments was from 20 to 350 °C. The experimental results were compared to the available literature correlations.

Previous work

The pressure gradient through packed beds was studied for a long time and a large number of correlations were proposed. The overview of the pressure drop correlations proposed by different authors is given in Table 1 together with the range of their applicability suggested by the authors. The most widely used equation for pressure drop calculation was proposed by Ergun [1]:

$$-\frac{\Delta p}{H} = 150\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu}{d_p^2}U + 1.75\frac{(1-\varepsilon)}{\varepsilon^3}\frac{\rho_f}{d_p}U^2 \qquad (1)$$

The equation consists of two added terms describing viscous and inertial pressure losses. The viscous effects are described by linear and the inertial effects by quadratic dependence on the fluid superficial velocity, U. The Ergun equation can be regarded as direct method of pressure drop calculation. The friction factor based on Ergun's equation is defined as:

$$f_p = \left(-\frac{\Delta p}{H}\right)\frac{d_p}{\rho_f U^2}\frac{\varepsilon^3}{1-\varepsilon} \qquad (2)$$

According to Eqs. (1) and (2), Ergun's equation for the particle friction factor is:

Table 1. Some important literature correlations for friction factor in packed beds of spherical particles

Reference	f_p or f_p'	Eq.	Re_p range
Ergun [1]	$f_p = \frac{150}{Re_p'} + 1.75$	(3)	$1\text{-}2.4\times10^3$
Macdonald *et al.* [4]	$f_p = \frac{180}{Re_p'} + 1.80$	(4)	-
Gibilaro *et al.* [5]	$f_p' = \left(\frac{18}{Re_p} + 0.33\right)\frac{(1-\varepsilon)}{\varepsilon^{4.8}}$	(7)	-
Rose [8]	$f_p' = \frac{1000}{Re_p} + \frac{60}{Re_p^{0.5}} + 12$	(8)	-
Rose and Rizk [9]	$f_p' = \frac{1000}{Re_p} + \frac{125}{Re_p^{0.5}} + 14$	(9)	-
Montillet et al. [7]	$f_p' = a\left(\frac{1-\varepsilon}{\varepsilon^3}\right)\left(\frac{D_c}{d_p}\right)^{0.2}\left(\frac{1000}{Re_p} + \frac{60}{Re_p^{0.5}} + 12\right)$ $A = 0.061$ ($\varepsilon<0.39$), $a = 0.050$ (($\varepsilon>0.39$); For $(D_c/d_p)>50$ term $(D_c/d_p)^{0.2} = 2.2$	(10)	$10\text{-}2.5\times10^3$ $3.8 \le D_c/d_p \le 40\text{-}50$
Kuerten, ref. in [10]	$f_p' = \left(\frac{25(1-\varepsilon)^2}{4\varepsilon^3}\right)\left(\frac{21}{Re_p} + \frac{6}{Re_p^{0.5}} + 0.28\right)$	(11)	$0.1\text{-}4\times10^3$
Hicks [11]	$f_p' = 6.8\frac{(1-\varepsilon)^{1.2}}{\varepsilon^3}Re_p^{-0.2}$	(12)	$500\text{-}6\times10^4$
Tallmadge [12]	$f_p' = \left(\frac{150}{Re_p}\frac{(1-\varepsilon)^2}{\varepsilon^3}\right) + \left(\frac{4.2(1-\varepsilon)^{1.166}}{\varepsilon^3}Re_p^{-1/6}\right)$	(13)	$0.1\text{-}10^5$
Lee and Ogawa [13]	$f_p' = \frac{1}{2}\left(\frac{12.5(1-\varepsilon)^2}{\varepsilon^3}\right)\left(\frac{29.32}{Re_p} + \frac{1.56}{Re_p^n} + 0.1\right)$ where $n = 0.352 + 0.1\varepsilon + 0.275\varepsilon^2$	(14)	$1\text{-}10^5$

Table 1. Continued

Reference	f_p or f_p'	Eq.	Re_p range
Cheng [16]	$f_p = \frac{AM}{Re_p'} + BM$, $M = 1 + \frac{2}{3}\frac{1}{1-\varepsilon}\frac{d_p}{D_c}$, $A = \left[185 + 17\frac{\varepsilon}{1-\varepsilon}\left(\frac{D_c}{D_c - d_p}\right)^2\right]\frac{1}{M^2}$, $B = \left[1.3\left(\frac{1-\varepsilon}{\varepsilon}\right)^{1/3} + 0.03\left(\frac{D_c}{D_c - d_p}\right)^2\right]\frac{1}{M}$	(15a) (15)	-
Eisfeld and Schnitzlein [17]	$f_p = \frac{154M^2}{Re_p'} + \frac{M}{B}$, *M* by Eq.(15a), $B = \left[1.15(d_p/D_c)^2 + 0.87\right]^2$	(16)	$0.01\text{-}1.76\cdot 10^5$
Reichelt [18]	$f_p = \frac{150M^2}{Re_p'} + \frac{M}{B}$, *M* by Eq.(15a), $B = \left[1.5\left(d_p/D_c\right)^2 + 0.88\right]^2$	(17)	-
Zhavoronkov *et al.* [19]	$f_p = \frac{165.3A^2}{Re_p'} + 1.2B$, $A = B = 1 + \frac{1}{2\left(D_c/d_p\right)(1-\varepsilon)}$	(18)	-
Raichura [20]	$f_p = \frac{AM^2}{Re_p'} + BM$, *M* by Eq.(15a), $A = \frac{103}{M^2}\left(\frac{\varepsilon}{1-\varepsilon}\right)^2\left[6(1-\varepsilon) + 80(d_p/D_c)\right]$, $B = \frac{2.8}{M}\frac{\varepsilon}{1-\varepsilon}\left[1 - 1.82(d_p/D_c)\right]^2$	(19)	-

$$f_p = \frac{150}{Re_p'} + 1.75 \qquad (3)$$

where $Re_p' = (\rho_f U d_p)/(\mu(1-\varepsilon))$.

For spherical particles, d_p in Ergun's equation is the diameter of the particles that constitute the packed bed, while for non-spherical particles d_p is usually taken to be the surface-volume diameter of the particles, d_{sv}. The experiments used to derive Ergun's equation were performed using monodisperse spherical and non-spherical particles in the range of Re_p' numbers $1 < Re_p' < 2400$. Some recent studies were conducted in order to extend the use of Ergun's equation to the polydisperse particles systems taking into account the particle size distribution [2,3].

Macdonald *et al.* [4] reviewed the applicability of Ergun's equation and proposed a slight change in the constants 150 and 1.75 of Eq. (3). They proposed these constants to be 180 and 1.8-4.0, respectively. Different values in the interval of 1.8-4.0 were proposed to be used depending on the particles roughness, but no roughness criterion according to which the values should be chosen was proposed. For smooth particles, the value 1.8 should be used [4]. The equation of Macdonald *et al.* [4] is shown in Table 1 (Eq. (4)).

Based on the theoretical considerations, Gibilaro *et al.* [5] proposed the pressure drop through packed beds to be calculated according to the equation:

$$-\frac{\Delta p}{H} = \left(\frac{18}{Re_p} + 0.33\right)\frac{\rho_f}{d_p}U^2\frac{(1-\varepsilon)}{\varepsilon^{4.8}} \qquad (5)$$

where $Re_p = d_p \rho_f U/\mu$.

The particle friction factor based on this equation is defined as:

$$f_p' = \left(-\frac{\Delta p}{H}\right)\frac{d_p}{\rho_f U^2} \qquad (6)$$

According to Eqs. (5) and (6):

$$f_p' = \left(\frac{18}{Re_p} + 0.33\right)\frac{(1-\varepsilon)}{\varepsilon^{4.8}} \qquad (7)$$

It can be seen from Eqs.(2) and (6) that $f_p = f_p'\varepsilon^3/(1-\varepsilon)$.

Gibilaro *et al.* [5] observed that their correlation represents data in laminar regime equally well as Ergun's equation, but is superior to it in high voidage systems as well as in the range of high Re_p numbers ($Re_p > 100$), where Ergun's equation consistently over-predicts the observed friction factor.

Montillet *et al.* [6,7] discussed different equations proposed for f_p' and presented their own equation. They stated that Ergun's equation should not be used for $Re_p > 500\text{-}600$ because in the fully developed turbulent regime, the pressure drop is not proportional to the square of the superficial velocity. They suggested that the best way to represent the pressure drop was by Rose [8] and Rose and Risk [9] type equations (Eqs. (8) and (9) in Table 1). They modified these equations by adding a correlation factor based on bed voidage, ε, and the bed geometric aspect ratio, D_c/d_p (Eq. (10) in Table 1). They defined the range of applicability of Eq. (10) to $3.8 \le D_c/d_p \le 40$-50 and $10 < Re_p < 2.3\times10^3$. For $D_c/d_p \ge 50$, the term describing the effect of the geometric aspect ratio $(D_c/d_p)^{0.2}$ should be set to 2.2.

Hicks [11] has also investigated the applicability of Ergun's equation in the range of large Re_p numbers and concluded that the constants in Ergun's equation are dependent on Re_p number and that the equation should not be used for spheres for $Re_p > 500$. He proposed his own equation for particle friction factor for $Re_p > 500$ (Eq. (12) in Table 1).

Tallmage [12] has also shown that the range of applicability of Ergun's equation is $0.1 < Re_p < 500$. He extended this range to $0.1 < Re_p < 1\times10^5$ by modifying the turbulent term of Ergun's equation (1.75) to be a function of Re_p (Eq. (13) in Table 1).

Lee and Ogawa [13] proposed a correlation that includes the bed voidage as an important parameter (Eq. (14) in Table 1). Their equation has shown to represent the experimental data at high Re_p numbers well.

Allen *et al.* [14] reviewed the use of different correlations for pressure drop of packed beds of different spherical and non-spherical packing. They have shown that the particle shape, arrangement, packing method as well as surface roughness influence the pressure drop significantly. Nemec and Levec [15] investigated the single-phase flow through the packed bed reactors in the range of Re_p numbers of $10 < Re_p' < 500$ with dense and loose packing of different particles. They concluded that Ergun's equation represents a good approximation of the fluid flow through packed beds of spherical particles in the investigated Re_p' range, while it under-predicts the pressure drop over non-spherical particles under the same conditions.

Several authors [16-21] investigated the influence of D_c/d_p on the pressure drop in packed beds of particles. Cheng [16], Eisfeld and Schnitzlein [17], Reichelt [18], Zhavoronkov *et al.* [19] and Raichura [20] all used the form of the equation for particle friction factor f_p proposed by Ergun and given by Eq. (3), but with the difference that the coefficients in the equation are not constants, but are different complex functions of voidage, ε, and the column and particle diameters, D_c and d_p. Eisfeld and Schnitzlein [17] corrected Ergun's equation for wall effects by reviewing the data of many previous studies. They concluded that the wall effect is dependent on Reynolds number. In the range of low Reynolds numbers, the pressure drop is increased due to wall effect, while the reduced pressure drop occurs at high Reynolds numbers. The mentioned correlations are shown in Table 1, by the Eqs. (15)-(19). By the analysis of the mentioned correlations, it can be concluded that the effect of the ratio of the column diameter to the particle diameter is negligible for large values of D_c/d_p. This is illustrated in Figure 1, which shows the variation of f_p with D_c/d_p calculated by the correlation of Reichelt [18]. As can be seen, the effect of D_c/d_p is negligible for $D_c/d_p > 10$ and it decreases with the increase of Re_p'.

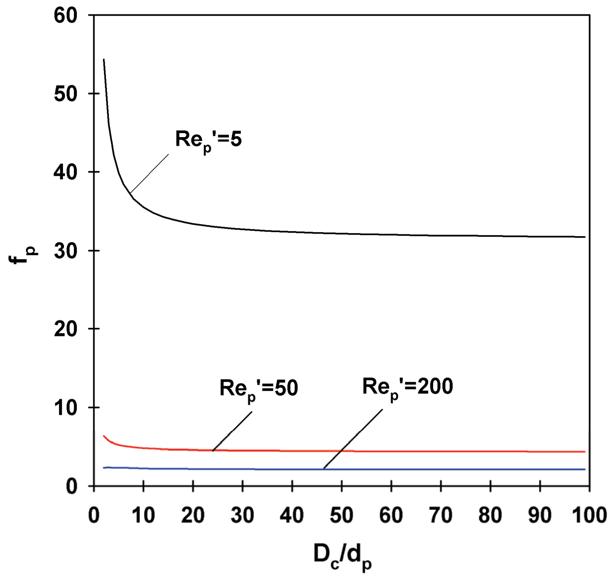

Figure 1. Variation of f_p with D_c/d_p calculated by the correlation of Reichelt [18].

The comparison between different literature correlations for f_p in beds of spherical particles is given in Figure 2. As some of the correlations require the knowledge of the bed voidage and bed to particle ratio diameter, the values of $\varepsilon = 0.4$ and $D_c/d_p = 50$ were assumed for comparison purposes. Note that all of the correlations were recalculated to the form of $f_p = f(Re_p')$, using Eqs. (2) and (6). As can be seen from the figure, different correlations give a relatively large span of particle friction factor, especially in the range of high values of Re_p.

EXPERIMENTAL

Two different columns were used for the experiments: a Plexiglas cylindrical column and a thermally insulated column. The Plexiglas column was used for room temperature experiments only, while the thermally insulated column was used for both room temperature and elevated temperature experi-

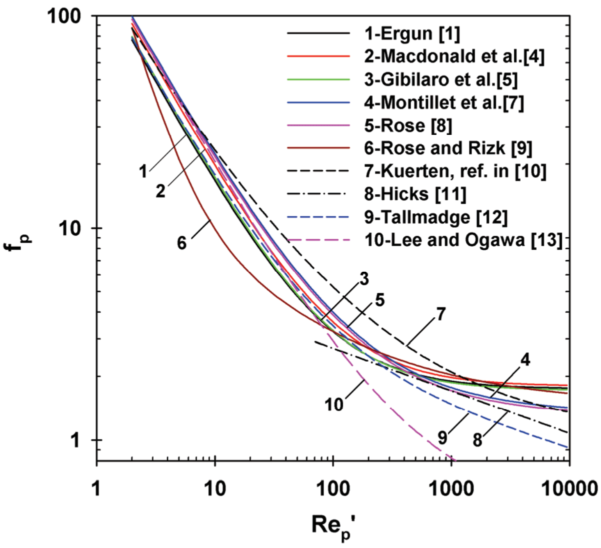

Figure 2. Comparison between different literature correlations for f_p in beds of spherical particles, ε = 0.4, D_c/d_p = 50.

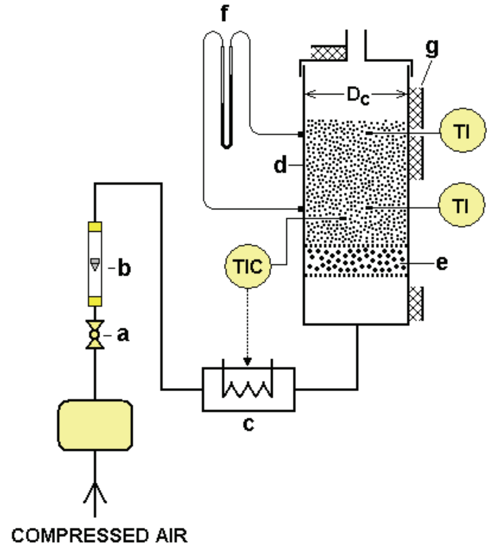

Figure 3. Experimental system (a - valve, b - rotameter, c - electric heater, d - column, e - distributor, f - manometer, g - thermal insulation, TIC -t emperature indicator and control, TI - temperature indicator).

ments. The Plexiglas cylindrical column was of the diameter of 62 mm and height of 300 mm. The thermally insulated column is schematically shown in Figure 3. The thermally insulated (g) packed bed column (d) was of the diameter of 119 mm and height of 300 mm. The column was equipped with a distributor and the calming section (e) in order to insure the uniform flow of air through the packed bed. The upward air flow was induced using a compressor. The compressed air first flew through the rotameter (b) and then through the electric air heater (c). The hot air was allowed to flow through the packed bed until the stable value of the bed bulk temperature was reached. The packed bed bulk temperature was regulated using temperature control system (TIC in Figure 3). The temperature was measured at the bottom and at the top of the column. The mean value of the temperature was than calculated and used for the calculation of thermo physical properties of air (density and viscosity). The variation of the temperature between the bottom and the top of the bed was less than 5 °C, so the effects of the temperature variation along the bed height were neglected. The pressure drop through the packed bed was measured using a water manometer (f). The height between the pressure taps was 200 mm. The measurements were performed for different particle diameters, air velocities and bed temperatures.

Seven kinds of mono-sized spherical glass particles were used. A total of 24 runs were conducted and a total of 1274 data points were collected. Bed particle Reynolds number varied between 2.2 and 502.6. All of the air superficial velocities used in the experiments were below the minimum fluidization velocity for the respective particles. The velocities applied were in the range of 0.03-0.94 U_{mf}. The ratio of the column diameter to the particle diameter (geometric aspect ratio) in the experiments was between 12.6 and 108.1, which is in the range of the negligible wall effects. The particle characteristics and range of the experimental conditions are summarized in Table 2. The effects of glass dilatation were neglected in the calculations, as the volume change of glass is less than 1% for the temperature raise of 300 °C.

RESULTS AND DISCUSSION

All of the results obtained in our experimental investigation are shown in Figures 4 and 5 together with the correlations tested. Figure 4 shows Ergun's equation [1], while Figure 5A and B show the other correlations used (Figure 5A - Reichelt [18], Eisfeld and Schnitzlein [17], Zhavoronkov *et al.* [19], Tallmadge [12], Gibilaro *et al.* [5], Macdonald *et al.* [4] and Cheng [16] correlations; Figure 5B - Lee and Ogawa [13], Rose and Risk [9], Rose [8], Montillet *et al.* [12], Raichura [20] and Kuerten [10] correlations). The correlations that do not show direct dependence on ε, as well as the correlations in which the variations with ε are very small, are shown as lines, while the correlations with direct dependence on ε are shown as points, calculated for the same conditions as the experimental data. The results are shown for seven types of spherical particles of different diameters. For three particle diameters, the experiments were conducted both at ambient temperature of 20 °C and at

Table 2. Particle characteristics and the range of experimental conditions.

d_p / mm	D_c / mm	ρ_p / kg m^{-3}	T_g / °C	ε	U / m s^{-1}
0.574	62	2679	20	0.3574-0.3829	0.0548-0.2333
1.039	62	2809	20	0.4001-0.4206	0.0286-0.5238
1.227	119	2661	20, 100, 200, 250, 300, 350	0.3759-0.4011	0.0278-0.7833
2.048	119	2515	20, 100, 200, 250, 300, 350	0.3634-0.4238	0.0276-0.9934
2.965	119	2533	20, 100, 200, 250, 300, 350	0.3742-0.4224	0.0461-0.9832
3.910	62	2555	20	0.3756-0.4265	0.0920-0.9793
4.908	62	2555	20	0.3846-0.4303	0.1104-0.8709

elevated temperatures between 100 and 350 °C. As can be seen from Figure 4, Ergun's equation predicts our experimental data well, for all the particle sizes and all temperatures.

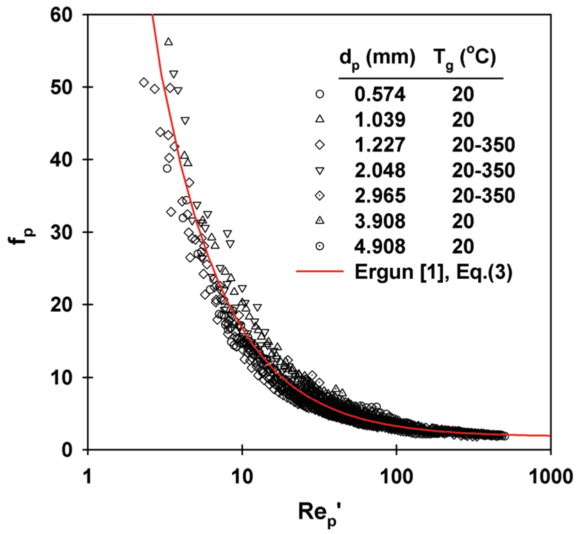

Figure 4. Relationship f_p vs. Re_p' at ambient temperature and at elevated temperatures, all data points.

The comparison between the experimental results and the selected literature correlations is given in Table 3. All of the literature correlations presented in Table 1 are used, except Hicks [11] correlation which is applicable only at $Re_p > 500$. The mean absolute deviation of the measured values of pressure gradient and the values obtained from the literature correlations were calculated according to the following equation:

$$\sigma = \frac{1}{N}\sum_{1}^{N}\left|\frac{(\Delta p / H)_{calc} - (\Delta p / H)_{measured}}{(\Delta p / H)_{measured}}\right| \tag{20}$$

where N is the number of data points, $(\Delta p/H)_{calc}$ and $(\Delta p/H)_{measured}$ are the calculated and the measured pressure gradients. The mean absolute deviations were calculated for all of the experimental data and also, separately, for the data measured at ambient temperature (T_g = 20 °C) and for the data measured at elevated temperatures (T_g, 100-350 °C).

As can be seen from Table 3, the overall best fit of all of our experimental data was obtained using the Ergun [1] correlation, with the mean absolute deviation of 10.90%. The mean absolute deviation for the

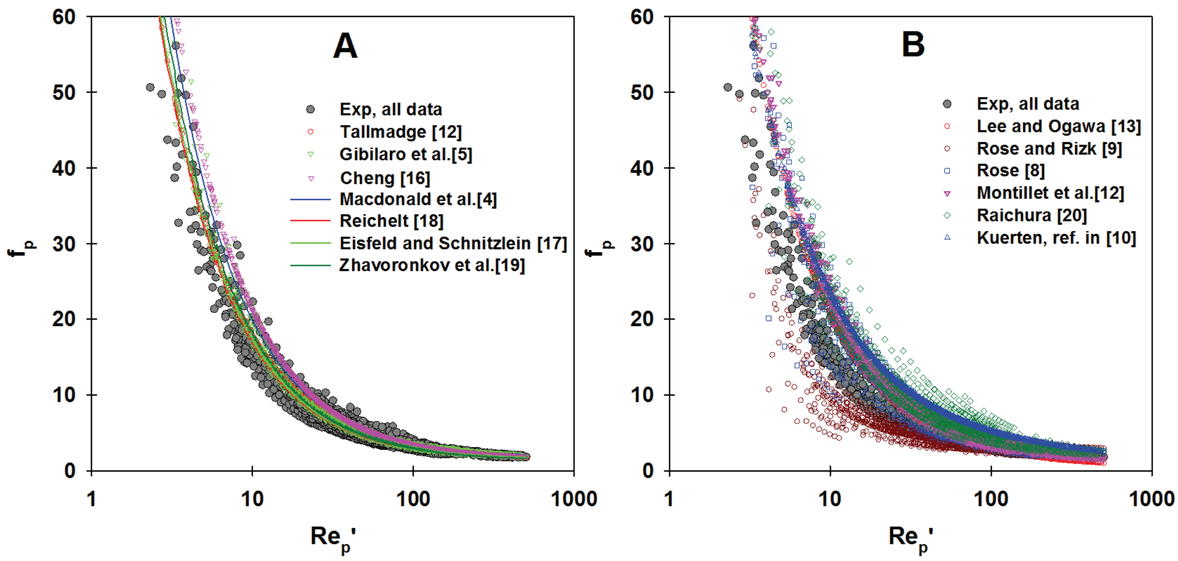

Figure 5. Experimental and correlated data of f_p vs. Re_p', all data points.

Table 3. Comparison of experimental data for pressure gradient with different correlations from literature for spherical particles.

Reference	σ / %, all data	σ / %, T_g = 20 °C	σ / %, T_g: 100-350 °C
	Number of data points		
	1274	781	493
Ergun [1]	10.90	9.77	12.38
Reichelt [18]	11.17	11.42	10.83
Eisfeld and Schnitzlein [17]	11.19	10.88	11.59
Zhavoronkov *et al.*[19]	12.92	12.33	13.69
Tallmadge [12]	13.32	9.49	18.31
Gibilaro *et al.* [5]	13.67	13.35	14.09
Macdonald *et al.*[4]	17.47	11.94	24.66
Cheng [16]	18.89	12.00	27.84
Lee and Ogawa [13]	20.19	18.17	22.81
Rose and Rizk [9]	22.78	27.18	17.07
Rose [8]	29.68	18.74	43.90
Montillet *et al.* [7]	31.19	24.04	40.50
Raichura [20]	41.99	36.27	49.44
Kuerten, ref. in [10]	56.95	48.50	67.93

room temperature data was smaller (9.77%) than for the data at elevated temperatures (12.38%). Although Ergun's equation performed best among the correlations tested, the correlations of Reichelt [18] and Eisfeld and Schnitzlein [5] gave better results for elevated temperature data only (10.83 and 11.59%, respectively). When all of the experimental data were tested, the correlations of Reichelt [18] and Eisfeld and Schnitzlein [5] had almost the same mean absolute deviation of 11.17 and 11.19%, respectively, which is almost the same as the mean absolute error of Ergun's equation for all of the data points.

The correlations of Zhavoronkov *et al.* [19], Tallmadge [12] and Gibilaro [5] gave similar results in correlating our experimental data (with mean absolute deviations between 12.92 and 13.67% for all of the experimental data tested). As the values of the Re_p numbers in our experimental system were in the range of 2.2-506, this similarity is in accordance with the observation of Gibilaro *et al.* [5] that their correlation represents data in low Re_p regime equally well as Ergun's equation. Also, as Tallmage [12] modified only the turbulent term of the Ergun equation, the results obtained using his equation in our range of Re_p numbers are similar to the results obtained using Ergun's equation. It should be noted that the correlation of Tallmage [12] actually gave better results than Ergun's equation for the room temperature data, while it performed much worse for the data at elevated temperature (the mean absolute deviations were 9.49 and 18.31% for the room temperature data and for the elevated temperature data, respectively). The other correlations used gave much larger mean absolute deviations, in the interval of 14.47 to 56.95% (Table 3).

For the majority of the correlations, the values of the mean absolute deviations calculated from the ambient temperature data are lower than the values calculated from the data obtained at elevated temperatures. The exceptions from this are the correlations of Reichelt [18] and Rose and Risk [9], which performed better at elevated temperatures. The values of the mean absolute deviations for elevated temperature data points in the cases of Tallmadge [12], Macdonald *et al.* [4], Cheng [16] and Rose [8] equations are two or more two times larger than the ones calculated for 20 °C data points.

CONCLUSIONS

The present study was conducted in order to investigate the particle friction factor for air flow through packed bed of spherical glass particles at ambient and elevated temperatures. The experiments were performed by measuring the pressure drop across the packed bed, heated to the desired temperature by the hot air. Also, the applicability of the available literature correlations was investigated.

The overall best fit of all of our experimental data was obtained using the Ergun [1] correlation, with mean absolute deviations of 10.90%. Ergun's equation gave better results in correlating the data at 20 °C with mean absolute deviations of 9.77% than the data at elevated temperatures, which was correlated with mean absolute deviation of 12.38%. The Tallmadge [12] correlation gave the best results in correlating the room temperature data, with the mean absolute error of 9.49%, which is just below the value of 9.77% for Ergun's equation. At elevated temperatures, Reichelt [18] and Eisfeld and Schnitzlein [5] correlations gave better results than Ergun's equation. All of the correlations used, except Reichelt [18] and Rose and Risk [9] equation, gave better results when applied to ambient temperature data than to the data at elevated temperatures.

Based on the results obtained, Ergun's [1] equation could be proposed if one equation should be used for friction factor calculation both at ambient and at elevated temperatures. For elevated temperatures only, Reichelt [18] correlation gives better results. The mentioned conclusions are valid in the lower range of Re_p numbers, *i.e.*, for $Re_p < 500$.

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Nomenclature

a constant in Eq. (17)
A, B parameters in Eqs. (17)-(21)
d_p packed bed particle diameter
D_c column diameter
g gravitational acceleration
f_p friction factor defined according to Eq. (2)
f_p' friction factor defined according to Eq. (6)
H bed height
M parameter in Eqs.(17)-(21), defined in Eq. (17a)
p pressure
Re_p $= (\rho_f U d_p)/\mu$, particle Reynolds number
Re_p' $= (\rho_f U d_p)/(\mu(1-\varepsilon))$, bed particle Reynolds number
T_g temperature of the gas
U superficial fluid velocity
U_{mF} minimum fluidization velocity (superficial)

Greek letters

ε voidage
μ fluid viscosity
ρ_f fluid density
ρ_p particle density
σ mean absolute deviation

Subscripts

f fluid
mF minimum fluidization
p particle

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NAUČNI RAD

PAD PRITISKA U PAKOVANOM SLOJU SFERIČNIH ČESTICA NA SOBNOJ I POVIŠENIM TEMPERATURAMA

Cilj ovog rada je bio eksperimentalno ispitivanje koeficijenta trenja fluid-čestice prilikom strujanja vazduha kroz pakovani sloj čestica, na sobnoj i povišenim temperaturama. Izvršeno je eksperimentalno merenje pada pritiska u pakovanim slojevima različitih temperatura zagrejanih korišćenjem vrelog vazduha. Kao materijal za pakovanje korišćene su sferične staklene kuglice 7 različitih prečnika. Temperaturni interval u kom su vršeni eksperimenti bio je od 20 do 350 °C, dok su poroznosti sloja iznosile od 0,3574 do 0,4303. Dobijeni rezultati korelisani su korišćenjem većeg broja literaturnih korelacija. Najbolje slaganje sa eksperimentalnim podacima pokazala je Ergunova jednačina [1], sa srednjim procentnim odstupanjem od 10,90%. Ergunova jednačina je dala bolje rezultate prilikom korelisanja podataka na sobnoj temperaturi (srednja procentna greška 9,77%), dok je korelisanje podataka na povišenim temperaturama izvršeno sa greškom od 12,38%. Većina testiranih literaturnih korelacija je dala bolje rezultate pri korelisanju podataka dobijenih na sobnoj temperaturi u odnosu na podatke dobijene na povišenim temperaturama. Na osnovu dobijenih rezultata, predlaže se korišćenje Ergunove jednačine za izračunavanje koeficijenta trenja fluid-čestice kako na sobnoj, tako i na povišenim temperaturama.

Ključne reči: pad pritiska, pakovani sloj, povišena temperatura.