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Influence of Rheological And Physical Properties of Particles And Liquid Media To Compute Terminal Fall Velocity: A Review

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Abstract

The hydrodynamic demeanor of falling particles and the liquid media in which they fall, supported by data analytics, is indispensable in the computation of the terminal falling rate. which is a critical concept in many civil engineering disciplines. The application of terminal settling velocity becomes vital to prevent the settling of microplastic particles (< 5 mm in size), several metal particles, polymers, etc.; especially those of irregular shape. Past research has explicated and inveterate that the downward terminal motion of a particle is a function of the rheological characteristics such as specific mass, density, shape, size, sphericity, projected area, etc. of the dropping particle, as well as the mass, kinetic viscosity, temperature, etc. of the fluid through which it falls. The actual circumstances of falling particles and the fluid through which they descend during the settling process deviate significantly from the conditions anticipated in Stoke's revolutionary work in the computation of fall velocity; hence, the falling rate is highly impacted. The current research intends to integrate the work of several researchers on the influence of particle and liquid rheologic properties in the computation of fall velocity. The present research focuses on expanding the available literature, and applying current information to forecast the falling rate of irregular shaped particles, particularly a mixture of metals, polymers, microplastics, composites, and natural gravels, by suggesting data-driven method of particle characterization.

Keywords: Viscosity, characterization, shape factor, settling velocity, drag, buoyant force reynolds number, flow regime

INTRODUCTION

Numerous types of particles, such as natural sand, gravel, microplastics, metal tailings, etc., falling in a liquid column experience gravity, buoyancy, and drag forces; of which the latter two oppose the falling of the particle. Under the action of such forces, after falling for some distance, the particle attains a steady-state falling rate called terminal fall velocity. This terminal velocity finds a place in the design of several civil engineering systems (1).

The settling rate of particles in a quiescent liquid medium varies due to particle density, shape, size, volume, etc., and the specific gravity, viscosity, density, Reynolds number, etc. of the fluid in which it is settling (2). The pioneering work to put forth a notion of fall velocity and factors that cause it to deviate was done by Stokes in 1851, subjected to assumptions on the shape of particles, flow regime, etc. (3).

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Stokes' findings prompted numerous scholars to dig further into the assumptions he used to derive the link between coefficient drag and fall velocity. Since then, experiments on spherical particles and flow regimes outside of Stokes' predicted range have been conducted. The researchers attempted to anticipate the particle's settling velocity and the link between drag and the Reynolds number. The prediction of the settling rate of irregular shaped particles in liquids of varying densities and viscosities, on the other hand, has yet to find a place in study.

The objective of the current research is to provide a result-driven comprehensive literature review on the prediction of the falling rate of irregular shaped particles carried by past researchers.

FALL VELOCITY: FACTORS INFLUENCING

Particle Rheology

The first attempt at calculating the settling velocity of a particle, as proposed by Stoke, was assumed to be a sphere (4). However, in practical situations, there are many deviations from the Stokes assumptions. They are:

***Shape*:**

The drag on a falling particle in Stoke's range is independent of particle thickness as long as the particle is not long rod-like in form. As a result, the form of a single particle is described in terms of the following co-efficient:

i. Volume
ii. Projected Area
iii. Shape Factor

In non-spherical particles, the ratio of their maximum to minimum diameter should be equal to or less than four. Therefore, for irregular particles, the shape is expressed in terms of sphericity, and the Corey Shape Factor (CSF) (5) is given as

$$\Psi = \frac{(Surface\ Area\ of\ an\ Equal\ Volume\ Sphere)}{(Projected\ Area\ of\ Particle)} \tag{1}$$

$$CSF = \frac{c}{\sqrt{a.b}} \tag{2}$$

where, the variables (a, b, and c) are linear measurements along major, intermediate, and minor axes.

Size: If the particle is spherical, then only the diameter can be used effectively in the calculation of fall velocity. However, for irregular particles, one needs to discuss them at length.

Fall Diameter: A particle's settling diameter is demarcated as the diameter of a sphere with the same standard fall velocity, volume, and relative density as the particle being observed.

Nominal Diameter: This is demarcated as the diameter of a sphere with a volume equal to the particles being seen.

The fall diameter is a substitute to explain the basic concept of fall velocity. The ratio of nominal and fall diameters is proportional to each other, which is termed the hydraulic shape factor. It is evident that a sphere should have a unity shape factor, but resistance to fall increases when the shape factor deviates from unity; and (5) showed exactly the opposite concept with his eq. 2: resistance to flow increases when the shape factor decreases from unity. Later on, the suggestion given by (6) was preferred over the latter one.

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Particle Geometry

The particle and its size

A particle is defined as "any minuscule subdivision of matter with a dimension ranging from a few angstroms to a few millimeters." Particles are three-dimensional objects with three dimensions: length, width, and height. A single number that equals particle size cannot be used to describe a particle. As a sphere is a form that can be defined by a single number, most sizing approaches assume that the substance being measured is spherical (its diameter). The most important aspect of a particle is that it is a three-dimensional object that cannot be accurately represented by a single dimension such as radius or diameter. Particle size is determined by the diameter of an equivalent sphere with the same volume or mass as the genuine particle.

(7) observed that microplastics of size less than 5 mm, when joining the stream, remain in suspension and cause pollution in the water body. It is imperative to study the settling behavior of such polymer based microplastic particles. Similarly, the study of the falling rate of steal, zirconia, and glass particles of different shapes and sizes is equally important in the oceanic ecosystem, as opined by (8).

Martin defined an irregular particle's size as the length of the line bisecting the particle's largest cross-sectional area. Particle size was described by Feret as the distance between the particle's two most extreme locations (9, 10). The following are some of the limits of such a definition: If the distance between the particle's outermost edges remains constant but the rest of its arrangement changes, the Feret diameter will not change. An irregular particle's size or form cannot be described by such a description (11) as shown in Figure 1

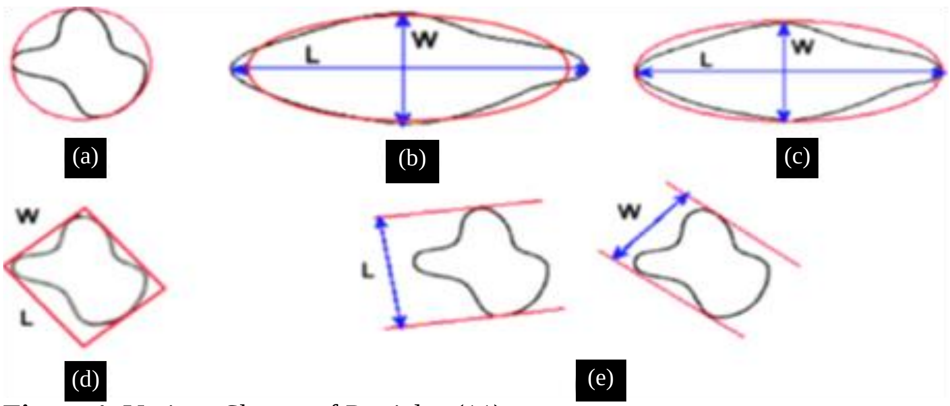

Figure 1. Various Shapes of Particles (11)

Nevertheless, the particle is signified by a sphere of variable extent; the extent of an irregularly shaped particle is described in terms of the size of an equivalent sphere. Because it just has one dimension, the diameter, the sphere is considered the simplest shape. Some of the relevant sizes of an equivalent sphere, according to the attribute picked, are:

a. A sphere with the equivalent volume as the particle.
b. The same-surface area as the particle.
c. a sphere with the same surface area as the particle per unit volume.

Size Analysis

Particle-size breakdown entails measuring and analyzing the three mutually orthogonal dimensions of a particle, which define the particle's three-dimensional form. It is significantly appropriate to quantify particle extent using only a distinct variable, such as the measurement of the intermediary particle axis. Once particle sizes are obtained, they are statistically studied so that particle extent dispersal and statistical characteristics can be related. The hydraulics of flow as well as bed load transfer rates are affected by the mean particle size on a streambed, a specific particle-size percentile, a distinctively large particle size, and the entire range of particle sizes.

a. Particle AxesThe span of particle axes (3D), orthogonal to each other, i.e., the lengthiest (a-axis), the intermediary (b-axis), and the shortest (c-axis) axis, are used to analyze particle sizes and shape characteristics (12). The need for a, b, and c-axes to actually be the lengthiest, intermediary, and shortest axes to be perpendicular to each other has been met. The three-axial measurement using microsope to compute the shape factor is a simple and good technique; however, it is subjected to the resolution of the eyepiece (13)
b. Particle DiameterThe term particle diameter, sometimes also called sieve diameter, is specified as a quantitative measurement along the three perpendicular axes (14)

Need for particle characterization

Particle characterization is the process of determining the form, size, surface characteristics, and mechanical properties of distinct particles. Particles can vary in sedimentation rate, diameter, aspect ratio, and convexity, and their morphologies can range from basic spheres to rods, needles, plates, and cubes. All of these elements have an impact on how a material behaves and are thus of significant interest to producers.

Shape Factor

The shape factor terminology is used to consider the effect of the particle in forecasting the falling rate of irregular-shaped particles. The shape factor is the representation of an irregular-shaped particle in terms of the dimension of a spherical particle. The strategies used to compute shape factors are as follows: (14).

a. Coefficient Based on VolumeHaywood has defined the volume constant of the particle as under:

$$\text{Volume constant} = \frac{\text{The volume of the particle}}{d^3} \tag{3}$$

He also defined the surface constant as follows: where d is the diameter of a circle with an area equal to the particle's projected area perpendicular to the axis,

$$\text{Surface constant} = \frac{\text{The surface area of the particle}}{d^2} \tag{4}$$

Other investigators have defined the following constant

$$\text{Andreasen's coefficient} = \frac{d}{\sqrt[3]{\text{The volume of the particle}}} \tag{5}$$

$$\text{Markwick's volume ratio} = \frac{\text{The volume of the particle}}{abc} \tag{6}$$

$$\text{Markwick's surface constant} = \frac{b}{d_n} \tag{7}$$

Where dn is the nominal diameter.

a. Coefficient Based on VolumeSphericity is defined as the ratio of a sphere's surface area to its equivalent volume as a particle to the particle's actual surface area (15). Sphericity will be equal to unity for a spherical particle and less than unity for any other form. Wadell's definition of sphericity was founded on good theoretical considerations, but he also recognized the concept's impracticality. The true surface area of the small particle is very difficult to obtain (12). Hence, sphericity was redefined by Wadell as

$$\text{Sphericity} = \left(\frac{\text{Volume of Particles}}{\text{The volume of circumscribing sphere}}\right)^{\frac{1}{3}} \tag{8}$$

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If dn, is the nominal diameter and ‘a’ is the major axis, then the above relationship reduces to the following simple form:

$$\text{Sphericity} = d_n/a \tag{8a}$$

the idea of sphericity developed by (16), which was a significant step forward in the description of particle form, but it has a flaw in that it does not account for particle thickness.

b. Coefficient Based on the Projected AreaSince the particle is most stable when the minor axis is vertical, the projected area perpendicular to the minor axis, i.e., the projected area in the plan in the most stable condition, is generally used. In this state, two types of coefficients are defined: the coefficient of roundness, the coefficient of circularity, and the coefficient of roundness.

While sphericity is associated with the silhouette of the particle as compared to the sphere, the term roundness is related to the sharpness of various corners and edges of the sediment particles. Hence, roundness is an index that gives a quantitative idea as to whether the edges and corners of the particles are round or sharp. Thus, a particle can be elongated or disc-like in its shape, and yet all its corners and edges can be well rounded, hence its high roundness.

The coefficient of roundness is termed "the ratio of the average radius of curvature of the several corners and edges to the radius of curvature of the maximum inscribed sphere or the nominal radius of the particle." Studies have shown that roundness is not an important factor in its dynamic behavior. The wearing of sharp corners and edges changes roundness markedly but affects spherically very little.

Other coefficients of roundness are:

$$\text{Cox's coefficient of roundness} = \frac{r_1}{\sqrt[3]{abc}} \tag{9}$$

Where r1 = Smallest radius of curvature in the projected area.

Cailleux's coefficient of bluntness $= r_1/a$

Tickell's coefficient of circularity = $\text{Projected area}/\text{Area of particle}$

c. Coefficient Based on the three axesAn investigation by (6, 17, 18) has conclusively shown that the fall of the particles is affected by their shape (19). This fact was noticed by Zegrzda as far back as 1934. As a result of these investigations, a shape factor defined as the Corey shape factor (CSF) is given by

$$\text{Corey Shape factor (CSF)} = \frac{c}{\sqrt{a*b}} \tag{10}$$

where, the variables (a, b, and c) are linear measurements along major, intermediate, and minor axes.

The above equation is most suitable for studying the impact of shape on falling rates. For a sphere, the value of the shape factor will be unity, and for any other shape, it will be less than unity. The flatness ratio is defined by Wentworth, Wadell, and Cailleux as follows:

$$\text{Flatness ratio} = \frac{(a+b)}{2c} \tag{11}$$

According to Cailleux, the value of the flatness ratio varies from 1.05 to approximately 10 for natural sediment. Markwick denies the modulus of flatness as c/b and the modulus of length as a/b, if a/b is greater than 1.8 the particle is considered long. If c/b is less than 0.6, the particle is called flat.

If real sediment particles were only available in a few forms, a CD versus Re curve for each shape may be developed. As a result, empirical relationships between particles, fluids, and fall velocity may be established. Because the number of possible forms is unlimited, the natural approach is to use a basic categorization system (16)

$$\text{C. S. F.} = \frac{d_3}{\sqrt{d_1 * d_2}} \tag{12}$$

where, d1 = Longest axis, d2 = Intermediate axis and d3 = Shortest Axis of the three orthogonal axes. In the same line, the importance of the orientation of irregular shaped particles was noted by (20). While analyzing the orientation of irregularly shaped particles, the author suggested the concept of three mutually perpendicular axis identifications to describe the particle. Yet, more analysis and validation are needed to analyze its effect on settling velocity. Furthermore, various writers have provided the shape factor formula in prior research. The shape factor equations are provided in Table 1 below, with the notations a, b, and c referring to the particle's biggest, intermediate, and shortest diameters, respectively (19).

Table 1. Formula for shape factor given by various authors (21)

Sr.No.	Authors	Abbreviation	Shape Factor
1	Krumbein (1942)	KSF	$\sqrt[3]{\frac{bc}{a^2}}$
2	Corey (1949)	CSF	$\frac{c}{\sqrt{ab}}$
3	Aschenbrenner (1956)	ASF	$\frac{13.392\sqrt[3]{\frac{c^2}{ab}}}{1+\left(\frac{c}{b}\right)\left(1+\frac{b}{a}\right)+6\sqrt{1+\left(\frac{c}{b}\right)^2\left(1+\left(\frac{b}{a}\right)^2\right)}}$
4	Sneed and Folk (1958)	MPS	$\sqrt[3]{\frac{c^2}{ab}}$
5	Janke (1966)	ESF	$\frac{c}{\sqrt{\frac{a^2+b^2+c^2}{3}}}$

Verification of the equations

Using the sample data, the shape factor has been obtained for the equations suggested by (5,19–23) . The results are depicted in the Figure. 2 & 2(a) and Table 2 below:

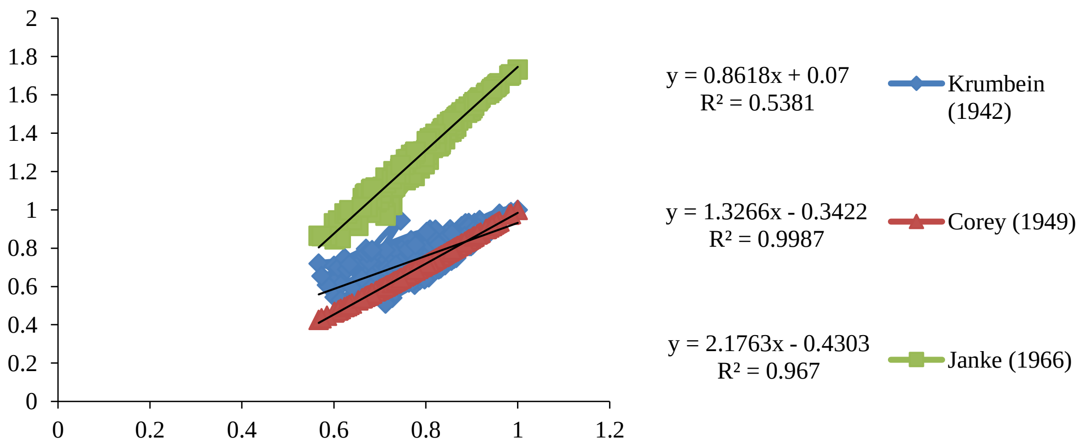

Figure 2. (a) Comparison of Shape Factor by selected researchers

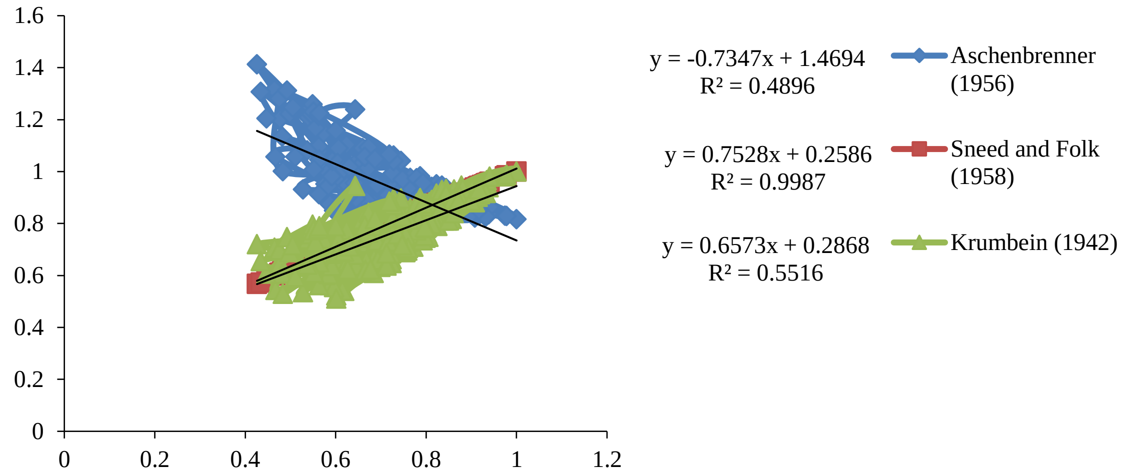

Figure 2. (b) Comparison of Shape Factor by selected researchers

Table 2. Mean, SD & SDE of calculated shape factor by various researchers

	Corey (1949)	Krumbein (1942)	Sneed and Folk (1958)	Aschenbrenner (1956)	Janke (1966)
Mean	0.719	0.759	0.800	0.941	1.310
Standard Deviation	0.121865	0.107845	0.091851	0.127935	0.20316
Sta. Error	0.008617	0.007626	0.006495	0.009046	0.014366

The correlation for computation of shape factor of irregular particles suggested by (5,20–23) has been used with three-axial measured data of 200 irregular particles. The standard deviation and standard error are minimum in the case of Sneed and Folk's correlation followed by Krumbein, Corey, Aschenbrenner, and Janke as shown in Table 2. However, from Figure 20(a) and 2(b), it is observed that the shape factor predicted using the equation given by Corey and Sneed and Folk is showing a strong correlation as R-value is 0.9987 (close to 1.0) as compared to other methods. This could be due to the similar approach adopted by them that emphasizes the shortest axis measurement to be in the numerator. From the consideration of standard deviation, standard error (Table 2), and R-value, it is evident that the correlation suggested by (5) gives the accurate shape factor that takes care of irregularity of particle during its fall in the liquid column and helps in predicting the fall velocity with excellent accuracy.

Fluid Rheology and Flow Regime

The rheological properties and flow regime become important factors in computing terminal settling velocity (using Stoke's law) when a particle falls in liquid media (14).

The thickness and viscidity change with the temperature of the fluid and need to be determined. (24) cited the effect of liquid temperature on fall velocity Figure. 3 and Table 3 and variations in density and viscosity of liquid at different temperature. Yet, it is always advisable to determine the viscosity using standard equipment.The correlation for computation of shape factor of irregular particles suggested by (5,20–23) has been used with three-axial measured data of 200 irregular particles. The standard deviation and standard error are minimum in the case of Sneed and Folk's correlation followed by Krumbein, Corey, Aschenbrenner, and Janke as shown in Table 2. However, from Figure 20(a) and 2(b), it is observed that the shape factor predicted using the equation given by Corey and Sneed and Folk is showing a strong correlation as R-value is 0.9987 (close to 1.0) as compared to other methods. This could be due to the similar approach adopted by them that emphasizes the shortest axis measurement to be in the numerator. From the consideration of standard deviation, standard error (table 2), and R-value, it is evident that the correlation suggested by (5) gives the accurate shape factor that takes care of irregularity of particle during its fall in the liquid column and helps in predicting the fall velocity with excellent accuracy.

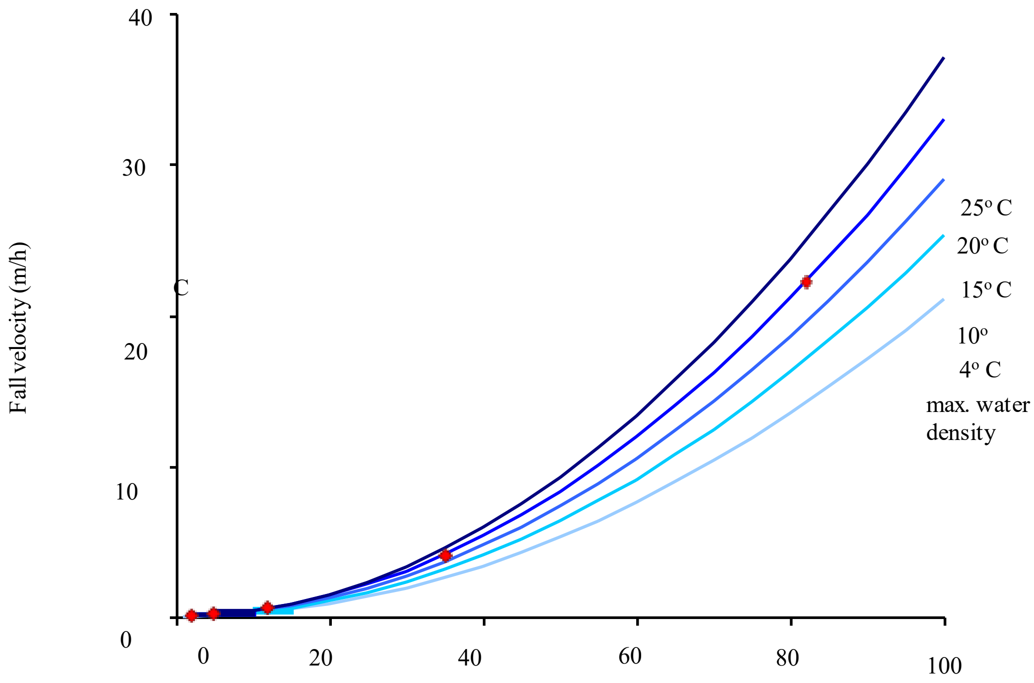

Figure 3. Particle size (micro m.) (24)

Table 3. Water density and dynamic viscosity as a function of temperature (24).

Temperature(in degree Celsius)	Density(in kg/cu.m.)	Dynamic viscosity(in Pascal – sec.)
4	1000	0.00156
10	1000	0.001304
15	999	0.001137
20	998	0.001002
25	997	0.00089
30	996	0.000798

The Stokes Law, which describes the basic equation to compute the fall velocity of a sphere, is largely affected by the flow condition called the Stokes Flow Regime. Also, such flow conditions can be very well described with the help of the Reynolds number.

Therefore, based on the Reynolds number, the following flow regime is classified:

- Re < 1.0 Stokes Flow Regime
- 1.0 < Re < 1000 Intermediate Law Regime (Laminar Flow Condition)
- 1000 < Re < 2 x 105 Transition (From Laminar Flow to Turbulent Flow Condition)
- Re > 2 x 105 Turbulent Flow Condition where boundary layer separation takes place

THE DRAG COEFFICIENT

The drag, which acts upon a particle in motion in calm liquid media, gets affected due to particle rheology and fluid properties. The computation of resisting force (drag) during the downward motion of a particle can be computed using theoretical concepts. Stoke proposed this computation first, obtaining a solution to the universal equation of motion by completely ignoring the inertial terms. Stokes Law states that "the force of viscosity on a spherical body falling with sufficiently small and constant velocity in a medium is directly proportional to the diameter of the sphere, the fall velocity attained by the sphere, and the coefficient of viscosity of the liquid."

$$F=3*d*v*\pi*\mu \quad (13)$$

The Stokes equation is valid in a regime flow governed by the condition Re < 0.1. But in most situations, the transition flow regime, regarding fall velocity, can be calculated using the equation suggested by (25)

$$C_D\,Re^2 = \frac{4}{3}\frac{d^3\rho(\rho_s-\rho)g}{\mu^2} \quad (14)$$

Thus, Re and fall velocity can be calculated as suggested in equation 6. They also suggested an equation for total drag on particles.

$$C_D = \frac{24}{Re} + \frac{3.6}{Re^{0.313}} \quad (15)$$

In an analytical solution and experimentation (26), an equation and later the graph of CD - Re by taking into account flattening and rounding of particles shed more light on the behavior of particles under liquid and the drag on a particle moving in liquid, which plays an important role in erosion, transportation, and sedimentation processes. They stated that drag is a complex phenomenon that is affected by the composition of the fluid, particle size, and form, and that the orientation of irregular particles in liquid is a major concern. In the case of laminar flow, however, eddies do not form as the particle descends. Therefore, a state of stable orientation will occur, and hence the original orientation will be retained by the particle as it falls.

$$CD = 4/3(\rho_k - \rho_f)/(\rho_f)\, g.(0.774 + 0.038.P).(CSF))^{2/3}.\frac{D_n}{u^2} \quad (16)$$

The correlation between analytical solutions and experimental values was complementary to each other. However, it could not incorporate the particles having a shape factor, CSF < 0.30. Also, for a particle with an asymmetric geometry, the terminal fall velocity could not be ascertained concerning its natural orientation while falling. For spherical and non-spherical particles, velocity charts for different-shaped particles were established by (27) through experimental work and put-forth a relation for the drag coefficient and terminal fall velocity.

Similarly, many other researchers worked on parameters that affect the drag on a particle moving in the liquid medium and suggested an empirical equation as shown in table 4. But these equations are of complex nature.

Table 4. Relations between Cd & Terminal Velocity (27)

Name of Researcher	**Suggested Equation**	**Conditions**
Khan and Richardson (1987)	$C_D = (2.25\mathrm{R_e}^{-0.31} + 0.36\mathrm{R_e}^{0.06})^{3.45}$	$\mathrm{R_e} = (0.23d_*^{0.018} - 1.53d_*^{-0.016})^{13.3} [\mathrm{R_e} < 3\times10^5]$
Flemmer and Banks (1986)	$C_D = \frac{2y}{R_e}10^E$ where, $E = 0.261Re^{0.369} - 0.105R_e{}^{0.431} - \frac{0.124}{1+(\log_{10}R_e)^2}$	$\mathrm{Re} < 8.6\times10^4]$
Turton and Levenspiel (1986)	$C_D = \frac{24}{R_e}\left(1+0.173R_e{}^{0.657}\right) + \frac{0.413}{1+16300R_e{}^{-0.1.09}}$	$[R_e < 2.6\times10^5]$
Zirang and Sylvester (1981)	$u_* = \frac{[14.51 + 1.83d * 3/2\,]\,1/2 - 3.81]2}{d\,*}$	
Turton and Clark (1987)	$u_* = [(\frac{18}{\mathrm{d}_*^2})^{0.824} + (\frac{0.321}{d_*})^{0.412}]^{-1.44}$	
Nian- Sheng Cheng (2008)	$C_D = \frac{24}{R_e}(1+0.27R_e)^{0.43}[1 - exp(-0.04R_e^{0.38})\,]w_* = \sqrt{4d_*/(3C_D)}$	

The constants of the suggested equation were modified using the method of curve fitting. An explicit equation was developed by (28) for predicting coefficient of resisting force (drag) for diverse unvarying shaped particles. However, the equation developed subjected to constant measurements about particle size. Furthermore, the equation was valid for the range of sphericity specific value of 0.006 and 1 and that of Reynolds number range from 10-2 to 105; depicting its limitations. Alike this work, (29) reviewed the available literature for non-spherical particles of isometric shape at a high Reynolds number. The shape parameter is used to compute the drag coefficient with the orientation of particles during settling. They concluded that to address the influence of high Reynolds Number on the irregular-shaped particle, modelling can be the probable solution.

Fall Velocity: Theoretical And Empirical Contributions

A relationship for calculating the terminal velocity of spherical particles in a Newtonian fluid directly given by (30).

$$u = (\beta d)^{\alpha} \tag{17}$$

$$\alpha = \frac{1+b}{2-b} \tag{18}$$

$$\beta = a^{-1(1+b)} \quad (19$$

Dividing the correlation curve between coefficient of drag and Reynold number into thirteen segments, author proposed to compute particle diameter by establishing exact relation between Cd and Re for each of the divided segment. This particle diameter is then used in computing settling velocities. However, appropriate curve fitting and confirmation of calculated terminal velocity were not addressed in his study.

An attempt was made by (31) in obtaining correlations between terminal settling velocity and coefficient of drag taking hemispherical particle and spherical segment having density ρ = 1557 kg/m3 in three different liquid media. He suggested an empirical equation for non-spherical particles that gives an inference that the settling rate of the non-spherical particle is greatly influenced by the initial orientation of particles.

$$u_t = \frac{\mu A_r^{0.569}}{2.606 \rho d_v} \tag{20}$$

$$A_r = \frac{d_v^2 g \rho (\rho_p - \rho)}{\mu^2} \tag{21}$$

$$Re = \frac{\rho d_v u_t}{\mu} \tag{22}$$

A periodic review from the year 1933-2007 on the research carried out by seventeen researchers relating to the development of new correlation between fall velocity and drag coefficient and Reynold number was studied by (32) and analyzed the equation suggested for the fall velocity of a particle. Later, the author developed the simple equation for fall velocity, which, concluded good correlation between observed and predicted values of velocity.

$$w = 0.033 \frac{v}{d} \left[\frac{d^3 . g(S-1)}{v^2}\right]^{0.963} \qquad \text{For } D \leq 10 \tag{23}$$

$$w = 0.051 \frac{v}{d} \left[\frac{d^3 . g(S-1)}{v^2}\right]^{0.553} \qquad \text{For } D > 10 \tag{24}$$

Research gap

From the detailed study of the work done by the researcher, it is significant to say that less work is reported on computation of terminal settling velocity of irregular shaped particle. The correlations between drag and Reynold number needs to develop for the purely irregular particles. This work would be more important in case of microplastics, metal tailings, which forms a part of many civil engineering, transportation engineering field.

DISCUSSION AND CONCLUSION

The background studies related to the conceptual understanding of fall velocity of particle has accentuated that despite being postulated by Stokes way back in 1851, the concept was very much subjected to the limitations of the assumptions made in the proposed equation of the fall velocity. Besides, though several researchers have recognized that the concept suggested by Stokes cannot give true behavior of the particle subjecting to change in shape and size and falling in the media having different Reynolds Number.

A literature study has revealed that in the case of irregular shaped particles, shape factor is an essential rheological property that affects the prediction of terminal fall velocity. Various approaches have been made in the computation of shape factor out of the equations suggested by (5,20–23) has been verified. It is observed that Corey and Sneed and Folks followed by Janke renders shape factor with behavior excellent accuracy in predicting terminal fall velocity of irregular particle. This research study intended to bring to the fore the fact that work on developing correlation between coefficient of drag and Reynolds number and fall velocity is required.

Nomenclature

- dvx/dy Rate of Shear
- U Average velocity of flow,
- D Diameter of Pipe.
- a, b & c The lengths of largest, intermediate and shortest mutually perpendicular axes of the particle.
- F Drag Force
- d Diameter of particle/sphere
- v Relative velocity between fluid and particle
- CD Coefficient of Drag,
- Re Reynolds Number.
- u, w Settling velocity of particle,
- u* , u* Dimensionless relative velocity in suspension
- d* , d* Dimensionless diameter
- P Particle – Fluid Parameter
- Q Particle-Fluid Parameter
- Xe Correction factor used for deviation from Stokes law
- CDM Modified Coefficient of Drag
- Co & δo Parameters of Spherical Particle
- ReM Modified Reynolds Number
- P Power Index,
- Dn, dn Nominal Diameter of particle
- CSF Corey Shape Factor
- pl, pi & ps Proportions of major, intermediate and minor axes and;
- Hr Relative Axial Uniformity
- Ws Settling velocity of the particle equivalent sphere
- V Volume of particle
- dA Surface equivalent sphere diameter

- Ap Projected surface area
- Pp Projected perimeter
- CDA CDA = Drag Co-efficient for actual projected surface area
- Ar Function of particle & fluid characteristics,
- dv Diameter of equivalent of sphere
- s Relative density,
- A1, B2, C1, A2 Coefficient Constants
- ut Terminal settling velocity
- ut∞ Terminal settling velocity in unbounded medium
- f Wall Factor

Greek Letters:

τ Shear Stress
μ Dynamic viscosity of fluid
ρ, ρf Density of fluid,
ψ Sphericity of a particle
ρs Density of Sphere,
γs Specific Weight of Sphere,
γf Specific Weight of Fluid,
μf Fluid Viscosity
λ Particle – to fluid density ratio
ρk Bulk density of particle,
Ø Sphericity,
Ø1 Crosswise sphericity
Ø11 Lengthwise sphericity
ν Kinematic viscosity
λ Ratio of particle dia (dp) to the column dia (Dc)

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