Editorial

Pressure Porosity Relationship: A Tool for Studying Physics of Tablet Compression

Ch. Niranjan Patra

Professor, Roland Institute of Pharmaceutical Sciences, Berhampur, ODISHA.

ARTICLE INFO

Key Words:
Pressure porosity, Kawakita equation, Heckel equation, Leuenberger analysis

ABSTRACT

Powder flowability and compressibility play a pivotal role in developing a tablet formulation. The parameters that are responsible to get the desired fluidity and compressibility of powders into tablets are; Particle size, Particle shape, Particle density, Nature of the powder (adhesive or cohesive). When the adhesive forces are more than the cohesive forces, the fluidity may be satisfactory, but not the compressibility. Similarly, the cohesive forces are more than adhesive forces, the fluidity is poor. Thus, these two pivotal parameters are necessary but behaviour wise, they are diagonally opposite. The principal problem in processing of tablets, is a crucial issue in the industries. The hidden or unseen or sometimes unexpected processing problems are in a complicated complex for the drugs. In the present editorial focus is given on use of different equations to study the pressure porosity relationships which in turn can be used in production of tablets with zero defects. The equations to study pressure porosity relationship such as Kawakita, Heckel, Leuenberger can be used to study the physics of tablet compression for synthetic drug powders, herbal powders, herbal extracts, excipients, co-processed excipients, crystals, co-crystals etc. The data generated from such studies will be of good help for industries specially tablet manufacturers.

Powder flowability and compressibility play a pivotal role in developing a tablet formulation. The parameters that are responsible to get the desired fluidity and compressibility of powders into tablets are 1. Particle size 2. Particle shape 3. Particle density 4. Nature of the powder (adhesive or cohesive). When the adhesive forces are more than the cohesive forces, the fluidity may be satisfactory, but not the compressibility. Similarly, the cohesive forces are more than adhesive forces, the fluidity is poor. These two pivotal parameters are necessary but behaviour wise, they are diagonally opposite. The principal problem in processing of tablets, is a crucial issue in the industries. When is adjusted somehow, to reach the desired parameters, ultimate goal being production into tablet dosage form from powders, the next phase is Q.C. Tests, vis-a-vis hardness, Disintegration Time (D.T), Friability, Weight Variation and Dissolution test. In other words, the excipients that are used in achieving the desired parameters for compression may contribute in a negative manner in the Q.C. tests. The hidden or unseen or sometimes unexpected processing problems are in a complicated complex for the drugs. In the present editorial focus is given on use of different equations to study the pressure porosity relationships which in turn can be used in production of tablets with zero defects.

The following equations are generally used for studying pressure porosity relationships;

1. Kawakita Equation
2. Heckel Equation
3. Leuenberger Analysis

These pressure porosity equations have been reported for the study of the pressure porosity relationship of excipients, co-processed excipients, crystals, co-crystals, pharmaceutical powders, herbal extracts and powders.

Kawakita Equation

Kawakita introduced an equation describing the relationship between the volume reduction of a powder column and the applied pressure. The Kawakita equation is written as,

$$P/C = (1/ab) + (P/a) \text{ ----------1}$$

Where, C = degree of volume reduction = $(V_0 - V)/V_0$

V_0 = initial volume

V = volume of powder column under the applied pressure P

a = maximum volume reduction

b = inclination towards volume reduction

Pressure can be replaced with number of tappings and hence the equation (1) can also be written as

$$N/C = (1/ab) + (N/a) \text{ ----------2}$$

Where, N is no of tappings.

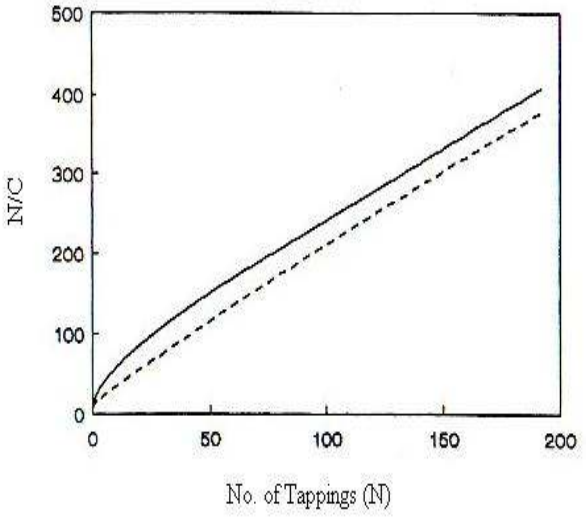

Figure 1: Typical Kawakita plot

Heckel Equation

The most commonly used equation in the pharmaceutical compaction studies was developed by Heckel [Heckel R. W, 1961a and Heckel R. W, 1961b] who considered that the reduction in voidage obeys a first order kinetics type of reaction with applied pressure. Heckel's equation is expressed as

$$\ln \frac{1}{1-\rho_r} = KP + A \text{ ----------3}$$

Where, ρ_r = relative density of the compact, K is slope and A is intercept can be obtained from **Figure 2.**

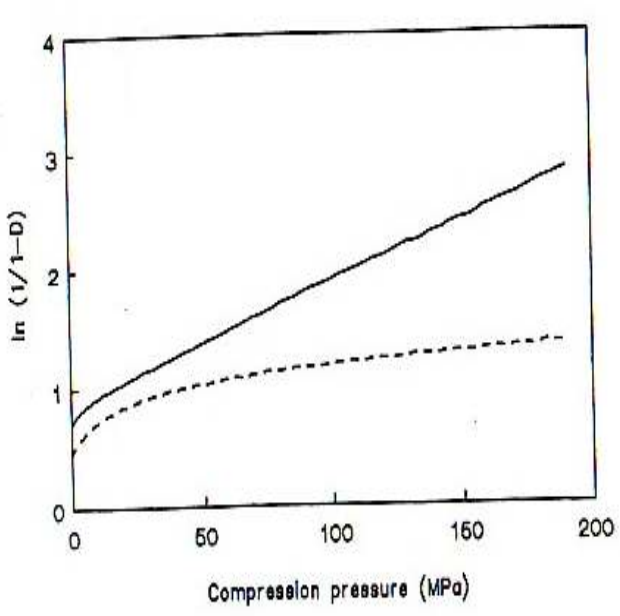

Figure 2: Heckel Plot

Heckel also proposed a relationship between the constants K, and the yield strength of the material, Y, as expressed by the following equation:

$$K = 1/3Y \text{ ----------4}$$

Later [Hersey JA, 1970] related the constant K to the mean yield pressure $P_{y.}$ as:

$$K = 1/P_y \text{ ----------5}$$

Hence K is inversely related to the ability of the material to deform plastically under pressure. The constant A is a function of the initial compact volume and can be related to the densification during die filling and particle rearrangement prior to bonding.

Characterisation of compressibility and compactility

Radial crushing strength (tensile strength)

The tensile strength of a cylindrical tablet can be calculated according to equation 6 where the geometry of the tablet is also considered.

$$\sigma_T = \frac{2 \cdot F_B}{\pi \cdot D_T \cdot h_T} \quad \text{----------6}$$

Where σ_T *is* radial crushing strength, F_B is crushing strength, D_T the diameter and h_T the thickness of the tablet. (figure 3)

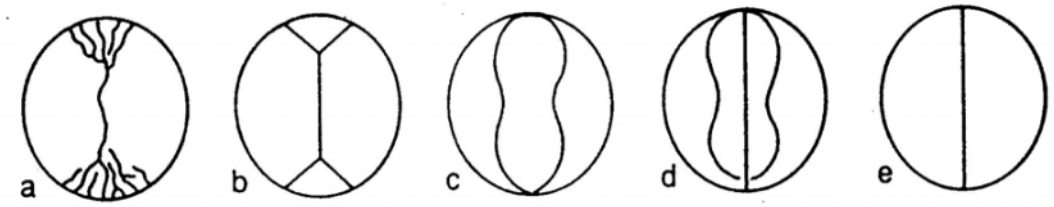

Figure 3: Different types of fractures of a compact by applying a diametrical force

Leuenberger Analysis

The physical model of powder compression proposed by [Leuenberger H,1980] connects the parameters compressibility and compactibility. It is assumed that the cross-sectional area of a cylindric compact consists of binding and non-binding points between particles. The crushing strength/tensile strength can be considered as the strength of a compact. The following equation can then be formulated as shown in equation

$$\sigma t = \sigma t \max\left(1 - e^{\gamma P}\right) \quad \text{-------7}$$

Where, σt is radial crushing strength at a certain forming pressure P, $\sigma tmax$ the maximum crushing strength, γ the compression susceptibility parameter and ρr the relative density. According to [Jetzer, 1986] the parameters $\sigma tmax$ and γ allow a characterisation of the different raw materials: The maximum crushing strength, $\sigma tmax$, represents compactibility, i.e., the ability of the material to build a compact with a sufficient strength under pressure, that cannot be exceeded even if an infinite high forming pressure, p, is applied. The compression susceptibility parameter γ is a constant specific for the compressibility of the material, i.e. the ability of the material to decrease its volume under pressure. The compressibility of a raw material can be characterised according to the parameters $\sigma tmax$ and γ as shown in Table 1.

Table 1: Values of *σtmax* and *γ* classified according to the type of deformation (Jetzer, 1983).

Parameters	Type of deformation under stress	
	Plastic	Brittle
Compactibility *σtmax (Kg/cm^{2})*	Small (0-10^{3})	Large (10^{3}-10^{4})
Compressibility *γ* *(Kg/cm^{2})*	Large (10^{-3})	Small (10^{-4})

The compactibility of a raw material can be characterised according to the parameters *σtmax* and *γ* as shown in table 2

Table 2: System for evaluation of the bonding properties of a substance with the parameters *σtmax* and *γ*

Compactibility Parameter *σtmax* (Kg/cm^{2})	Compression susceptibility *γ* (*Kg/cm^{2}*)	Bonding properties
Low (1-10^{3})	Low (10^{-4})	Poor to very poor
High (10^{3}-10^{4})	Low (10^{-4})	Moderate
Low (1-10^{3})	High (10^{-3})	Good
High (10^{3}-10^{4})	High (10^{-3})	Very good

Application in Formulation development

Hyung et al., 2010 studied the basic compressibility of excipients by using Kawakita and Heckel equation. They have selected lactose, calcium phosphate and microcrystalline cellulose as model excipients for the sudy. They reported that MCC deformed primarily by plastic deformation whereas lactose and calcium phosphate exhibited fragmentation and brittleness respectively. Haruna et al., 2020 evaluated the compaction and tableting properties of coprocessed MCC and crosspovidone and reported faster disintegration with in 15 min compared single use of MCC as excipient. Singh et al., 2011 evaluated the flowability and compressibility of *Termenalia chenbula* fruit powder by using kawakita, heckel and Leuenberger equations for direct compression and wet granulation formulations. Martin et al, 1999 determined the pressure susceptibility of polymer by using a modified Heckel model and revealed success. Patra et al, 2008 reported the consolidation behavior of *Rauwolfia serpentina* root powder using Kawakita, Heckel and Leuenberger equations for suitability to process into tablet dosage forms. Patra et al, 2015 studied direct compressibility potential of spherical crystals of aceclofenac and paracetamol.

Table 3. Application of pressure porosity equations in Tableting

Test	Material	Objective	Results	References
Kawakita Heckel	Lactose, calcium phosphate microcrystalline cellulose (MCC)	To study the basic compressibility of commonly used excipients	MCC = Plastic deformation Lactose = plastic and fragmentation Calcium phosphate = brittle	Choi D et al., 2020
Kawakita Heckel	Coprocessed MCC and crosspovidone	aim of this study was to evaluate the compaction and tableting properties	Disintegrated within 15 min and gave a rapid drug release when compared to MCC as a direct compression (DC) excipient.	Haruna et al., 2020
Kawakita Heckel Leuenberger	*Terminalia chebula* fruit powder,	examine the flowability and compressibility of *Terminalia chebula* fruit powder	*Terminalia chebula* fruit powder tablet can be prepared by using the direct compression and wet granulation techniques.	Singh et al., 2011
Heckel	Polymer	To determine the pressure suspectibility of polymer	new model has proven to be adequate for polymer tablets	Martin et al., 1999
Kawakita Heckel Leuenberger	*Saraca indica* bark powder	examine the original flowability, compressibility and compactibility	Tablet were prepared successfully	Singh et al., 2012

Kawakita Heckel Leuenberger	*Rauwolfia serpentina* root powder	to characterize the consolidation behavior.	Both wet granulation and direct compression method could be used successfully for developing tablet formulation	Patra et al., 2008
Kawakita Heckel Leuenberger	Spherical crystals of aceclofenac and paracetamol	to prepare directly compressible paracetamol (DCP) by nontypical spherical crystallization technique and spherical crystals of aceclofenac (SCA) by typical spherical crystallization technique	he combined formulation of SCA and DCP can be used for preparing tablet by direct compression method.	Patra et al., 2015

Conclusions

The equations to study pressure porosity relationship such as kawakita, Heckel, Leuenberger can be used to study the physics of tablet compression for synthetic drug powders, herbal powders, herbal extracts, excipients, co-processed excipients, crystals, co-crystals etc. The data generated from such studies will be of good help for industries specially tablet manufacturers.

References

1. Choi, D., N. Kim, K. Chu, Y. Jung, Jeong-Hyun Yoon and S. Jeong. Material Properties and Compressibility Using Heckel and Kawakita Equation with Commonly Used Pharmaceutical Excipients. *J Pharmaceutical Investigation.* 40 (2010): 237-244.
2. Haruna, F., Apeji, Y.E., Oparaeche, C. *et al.* Compaction and tableting properties of composite particles of

microcrystalline cellulose and crospovidone engineered for direct compression. *Futur J Pharm Sci.* 6, 35 (2020).

3. Heckel, R. W., An analysis of powder compaction phenomena. *Trans., Metall. Soc. Aime* 221, 1961b, 1001-1008.
4. Heckel, R. W., Density-pressure relationships in powder compaction, *Trans. Metall. Soc. Aime*, 221, 1961a, 671-675.
5. Hersey, J. A., Rees, J. E., Procedings of the 2nd Particle size Analysis Conf., Society for Analytical Chemistry, Bradford, 1970.
6. Jetzer, W. E., Compression characteristics of binary mixtures, *Int. J. Pharm.,* 31, 1986, 201-207.
7. Leuenberger, H., The compressibility and compactibility of powdered systems, *Int. J. Pharm*., 12, 1982, 41-55.
8. Martin Kuentz, HansLeuenberger Pressure susceptibility of polymer tablets as a critical property: A modified heckel equation. *J Pharm Sci.* 88 (2), 1999, 174-179.
9. Patra CN, Hemant Kumar Pandit, Satya Prakash Singh, M.Vimala Devi. Applicability and Comparative Evaluation of Wet Granulation and Direct Compression Technology to Rauwolfia serpentina Root Powder: A Technical Note. *AAPS PharmSciTech*, 9 (1), 2008.
10. Patra CN, Suryakanta Swain, Sauravo Mahanty, Kahnu Charan Panigrahi. Design and characterization of aceclofenac and paracetamol spherical crystals and their tableting properties. *Powder Technology* 274 (2015) 446–454.
11. Singh Satya Prakash, Ch Niranjan Patra and Subas Chandra Dinda. A Systematic Study on Processing Problems and in vitro Release of Saraca indica Caesalpiniaceae Bark Powder Tablets. *Tropical J Pharm Res*. 11 (3): 2012, 387-395.
12. Singh Satya Prakash, Patra Ch N, Santanu C, Hemant Kumar P, Patro VJ, Devi MV. Studies on Flowability, Compressibility and In-vitro Release of Terminalia Chebula Fruit Powder Tablets. *Iran J Pharm Res*. 2011; 10 (3):393-401.
13. Singh Satya Prakash, Ch Niranjan Patra, Chakraborty Santanu, Pandit Hemant Kumar, V Jagannath Patro, and M Vimala Devi Studies on Flowability, Compressibility and *In-vitro* Release of *Terminalia Chebula* Fruit Powder Tablets. *Iran J Pharm Res*. 2011; 10(3): 393–401.