Detachment and recovery index: A new parameter measuring powder compressibility

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Abstract
This investigation introduces a simple and reliable approach to measure the compressibility of some direct compression excipients in tablet systems made from compressible components. The claim made here is that: the total reduction, $\Delta L_T$, in the thickness of a tablet batch due to compression at a confined machine settings is the integral sum of small reductions generated by the compressible components in the batch. The reduction value, $\Delta L_E$, generated by a single or a blend of excipients in a batch could be calculated and was found to correlate to its concentration, $C$, by the relation: $\Delta L_E = A_E C^x$. The constants $A_E$ and $x$ concern the reduction tendency, RT, of the excipient particles due to compression, and detachment and recovery index (DRI), respectively. Some physicomechanical parameters characterizing the compression behavior of an excipient in a tablet batch could be determined and were found to be functions of the determine DRI of the excipient in the batch.

Key words: Compression, Density, DRI

INTRODUCTION

Compressibility of pharmaceutical powders and granules has been a subject of interest to many workers in pharmaceutical technology field since the sixties of the last century. Mani et al.[1] and Panny[2] reviewed and discussed the different models and equations proposed to measure the compressibility of powders and granules. The published models[3-8] focused the relationship between the compression pressure and the density of the produced compacts. Mani et al. mentioned that the most commonly used models are Heckel,[3] Kawakita and Ludde,[4] and Cooper–Eaton[5] models. Comoglu[6] pointed out that Heckel and Kawakita and Ludde models have not been proven to be successful in relating the densification behavior to the physicomechanical properties of the materials. Moreover, the Heckel model produces curved not linear plots whereas the Kawakita and Ludde model works best for only limited range of materials. Although the equations mentioned in these two models appear very different, it has been mathematically shown that for pressures that are relatively low compared to the yield strength, they are identical in form. Although Cooper–Eaton model provides best fit to compression data, its application is limited to one component system.[9] In a simple approach, Aly[10] showed the compression degree of a powder bed was a function of the free asperities available on the surface of the powder under compression.

The thrust of the present study is to introduce a simple and reliable model to measure the compressibility of excipients in tablet systems made of compressible components. Applying this model would minimize the use of instrumented tabletting machines which need calibration and some special handling.

MATERIALS AND METHODS

Oxytetracycline hydrochloride (OTH), the model of auto-compressible drug material was received from Cid, Assiut Branch, Assiut, Egypt. The direct compression excipients namely, microcrystalline cellulose, MCC, given by Food Manufacture Centre, FMC, Co., Pensylvania, PA, USA; the free flowing spray crystallized maltose and dextrose,
The formulations prepared with star-x were lubricated with 2% (w/w) stearic acid to produce hard tablets. The other formulations were lubricated with 2% (w/w) magnesium stearate. The lubrication process was carried out for 5 min just prior to compression using the local drum mixer. A single punch tableting machine (Manesty Machines Ltd., Liverpool, UK) fitted to flat faced punches was adjusted to compress tablets of 0.1 g mean weight and 6.4 mm mean diameter, and of the highest mechanical properties (mainly crushing load and friability) that could be achieved from the batch formulated with the largest concentration of a single or blend of excipients. The machine settings were kept constant throughout compressing the batches prepared from the lower concentrations of the same single or blend of excipients. It was necessary to readjust the machine settings whenever formulations of a new single or blend of excipients was compressed. At each confined machine settings, a control tablet batch was compressed from lubricated OTH powder. Altogether, 300 tablets were compressed from each batch. Applying this compression technique would minimize the fluctuation in compression pressure due to particle size variation. Having been compressed, the tablets were equilibrated over silica gel for 24 h prior to carrying out the evaluation tests to allow for elastic recovery, hardening, and avoid measuring the falsely yield values.

Evaluation of Tablets

Uniformity of weight and thickness

The produced tablets were evaluated for the weight and thickness uniformity. A sample of 20 tablets randomly collected from a given batch was used for the test. The tablets were individually and accurately weighed. The evaluation was carried out in accordance with BP 2000 specification. The thickness of each weighed tablet was determined using a dial micrometer.

Calculation of \( \Delta L_p \) of an excipient in a tablet batch.

The total reduction, \( \Delta L_p \), in the thickness of a tablet batch due to compression is generally given by

\[
\Delta L_p = L_o - L_f
\]

where \( L_o \) and \( L_f \) are the thicknesses of the tablet batch before and after compression, respectively. \( L_o \) is calculated as

\[
L_o = (4\omega \Sigma_i x_i \pi d^2 \Sigma_i (\rho_{B,i})),
\]

where \( \omega \) stands for the mean weight of the compressed tablet batch; \( d \) is its mean diameter; \( x_i \) stands for the weight fraction of the compressible component \( i \) in the tablet and \( \rho_{B,i} \) is its bulk density, respectively. Accordingly, Eq. (1) can be rewritten as

\[
\Delta L_p = (4\omega \Sigma_i x_i \pi d^2 \Sigma_i (\rho_{B,i}))-L_f
\]
It is claimed in this investigation that $\Delta L_d$ is the sum of small reductions generated by the compressible components in the tablet batch which in this instance are the drug and excipient(s). Equation (3) is thus simply rewritten as

$$\Delta L_d = \Delta L_x + \Delta L_y.$$  (4)

The reduction in the thickness, $\Delta L_d$, effected by the drug in a given batch is calculated from the control tablet batch (compressed from the lubricated drug only) of the set wherefrom the given batch is taken as follows: According to Eq. (2) $L_{d'}$ of the control batch of a given set is calculated as

$$L_{d'} = \frac{4\pi D}{\pi d} \rho_d \rho_b,$$  (5)

where $d$ stands for the mean weight of the control batch, $d'$ is its mean diameter, $\rho_d$ represents the weight fraction of the drug in the tablet and $(\rho_b)^D$ is the drug bulk density, respectively. $\Delta L_d$ is given by

$$\Delta L_d = L_{d'} - L,$$  (6)

where $L$ is the thickness of the finished control tablet batch. Eq. (6) can be rewritten as

$$\Delta L_d = 4\pi D \rho_b - L.$$  (7)

Dividing Eq. (7) by $wx_d$ yields

$$\Delta L_b = \frac{4\pi D \rho_b - L}{wx_d},$$  (8)

where $\Delta L_b$ (mm g$^{-1}$) is the reduction in the height of a column of 1 g lubricated drug powder compressed at the same confined machine settings. $\Delta L_b$ is practically impossible to obtain. Each set of the compressed batches has its $\Delta L_b$ value calculated from its control batch. This $\Delta L_b$ is employed as a reference to calculate $\Delta L_d$ value affected by the drug in a batch taken from a set. $\Delta L_d$ for a given batch is calculated as

$$\Delta L_d = m \Delta L_b.$$  (9)

where "m" is the weight (g) of the drug material in the batch. According to Eq. (4), $\Delta L_d$ is given by

$$\Delta L_d = L - m \Delta L_b.$$  (10)

**RESULTS**

**Physical Properties of Powder Materials**

The powders used in this investigation are of wide size variation and, accordingly, of varying surface areas. They possessed adequate flow rates and repose angles ranging from 1.0 to 3.5 g s$^{-1}$ and from 26° to 48°, respectively, which characterize the powder of low flow properties. Blends of excipients did not show improved flow properties. This is shown in the data listed in Table 1.

**Physical Properties of Compressed Tablets**

**Uniformity of weight and thickness**

The data given in Table 2 show that the batches compressed with star-x and MCC/Celutab blend were uniform in weight and complied with the BP 2000. The uniformity of thickness of the studied batches was examined as an additional control of tablet uniformity. The variation in thickness of the studied batches was parallel to those variations in weight.

**Mechanical Properties of Tablets**

**Porosity, crushing load, and friability**

The porosity fraction, $\varepsilon$%, of a given tablet batch was calculated from

$$\varepsilon = \frac{1 - V_e}{V_w},$$  (11)

where $V_e$ stands for the true volume of the excipient(s) in the given batch. $V_e$ is given by

$$V_e = \Sigma w/\rho_p$$

**Table 1: Some physical properties of oxytetracycline hydrochloride (OTH), powder and the named direct compression excipients used to manufacture tablets**

| Material used                   | Mean particle diameter, $\mu$m | Flow rate, g s$^{-1}$ | Repose angle, degree | Density, g cc$^{-1}$ | Surface area, cm$^2$10$^{-1}$g$^{-1}$ | Moist. cont. w/w (%) | Tapping fraction, $\mu$f (%), § |
|---------------------------------|-------------------------------|----------------------|---------------------|----------------------|---------------------------------------|----------------------|----------------------------------|
| OTH                             | 75                            | 3.60                 | 26.51               | 1.14                 | 0.72                                  | 7.01                 | 2.73                             | 71.0                            |
| Microcrystalline cellulose, MCC | (A)                           | 83                   | 1.12                | 48.00                | 1.50                                  | 0.92                 | 0.34                             | 4.45                            | 36.0                            |
| Celutab                         | (B)                           | 342                  | 1.05                | 32.00                | 1.72                                  | 1.10                 | 0.68                             | 1.02                            | 7.85                            | 62.0                            |
| Star-x                          | (C)                           | 113                  | 3.50                | 28.50                | 1.52                                  | 0.96                 | 0.69                             | 3.49                            | 9.11                            | 72.0                            |
| (A+B)                           |                               | 1.22                 | 33.00               |                     |                                       |                      |                                  | 40.0                            |                                 |
| (B+C)                           |                               | 1.21                 | 32.00               |                     |                                       |                      |                                  | 62.0                            |                                 |
| (A+C)                           |                               | 1.50                 | 33.00               |                     |                                       |                      |                                  | 61.0                            |                                 |

*Sieving technique, + Mean of 10 determinations using funnel technique, § Mean of three determinations using a pycnometer calibrated at room temperature, § Calculated value, ** Dry weight basis
where \( w_i \) and \( \rho_i \) represent the weight fraction of the component (i) in the tablet and its true density, respectively. Table 2 shows the porosity of a tablet batch decreased as the excipient concentration, \( C_i \), in the batch increased. Celutab produced the least porous tablets (porosity ranged from 9.3% to 5.1%). MCC produced less porous tablets. The porosity of the tablets ranged from 9.3% to 5.1% where star-x produced porous tablets. Tablets compressed with star-x blends with celutab or MCC possessed improved levels of porosity fractions. However, more porous tablets were compressed from MCC/celutab blends.

Table 2 also shows that the crushing loads, \( H_i \), generally increased as \( C \) increased in a tablet batch. Tablets compressed from MCC and celutab possessed almost the same level of crushing load. Star-x produced harder tablets. Blends of excipients produced tablets of higher levels of crushing Load.

It is clearly seen in Table 2 that the friability, \( F_i \), decreased as \( C \) increased in a given tablet batch. Tablets produced with star-x showed the least friability level followed by those tablets produced with celutab. More friable tablets were produced from MCC. Celutab/star-x blend.

Table 2 also shows that the tablets produced with MCC disintegrated after relative long times. Contrary, star-x and celutab, in this order, produced fast disintegrating tablets. Batches produced with blends of excipients generally disintegrated after short times.

**Measuring Excipients Compressibility**

The reduction in tablet thickness contributed by an excipient in a batch denoted as \( \Delta L_e \) and calculated as shown in Table 3 fits to the relation:

\[
\ln \Delta L_e = A_e + x \ln C,
\]

(12)
Table 3: The analysis of the data obtained on the weights and dimensions of OTH tablets prepared with single and 1:1 binary blends of excipients

| Excipient Name | Conc. (% w/w) | Loose thickness of Drug Excipient | Total loose thickness | Comp. thickness | Displacement value UPDV* | Reduction by Drug Excipient | % reduction contrib. by excip | Regression of % ΔL<sub>E</sub> on C | Intercept | Slope, x | r | Value |
|----------------|---------------|----------------------------------|----------------------|----------------|-------------------------|-----------------------------|----------------------------|-----------------------------|-----------|--------|----|-------|
| MCC (A)        | 32.6          | 0.135 0.244                      | 0.389 0.280          | 0.099 0.540   | 0.054 0.035             | 0.043 0.056                 | 56                          | 5.93          | 0.63   | 0.995 | 254 |
| 42.0           | 0.166 0.200   | 0.366 0.268                      | 0.098               | 0.035 0.063   | 0.031 0.077             | 0.038 0.042                 | 73                          | 14.38       | 0.43   | 0.987 | 983 |
| 49.0           | 0.191 0.173   | 0.364 0.256                      | 0.108               | 0.038 0.042   | 0.031 0.077             | 0.038 0.042                 | 73                          | 14.38       | 0.43   | 0.987 | 983 |
| 19.6           | 0.069 0.299   | 0.368 0.288                      | 0.080               | 0.038 0.042   | 0.031 0.077             | 0.038 0.042                 | 73                          | 14.38       | 0.43   | 0.987 | 983 |
| Celutab (B)    | 3.6           | 0.115 0.249                      | 0.364 0.283                      | 0.081 0.390   | 0.032 0.049             | 0.028 0.069                 | 71                          | 14.38       | 0.43   | 0.987 | 983 |
| 42.0           | 0.152 0.219   | 0.371 0.274                      | 0.097               | 0.028 0.069   | 0.024 0.081             | 0.026 0.035                 | 77                          | 14.38       | 0.43   | 0.987 | 983 |
| 19.6           | 0.065 0.246   | 0.311 0.250                      | 0.061               | 0.026 0.035   | 0.024 0.081             | 0.026 0.035                 | 77                          | 14.38       | 0.43   | 0.987 | 983 |
| Star-x (C)     | 32.6          | 0.110 0.207                      | 0.317 0.242                      | 0.075 0.320   | 0.022 0.053             | 0.019 0.061                 | 77                          | 12.75       | 0.48   | 0.985 | 851 |
| 42.0           | 0.142 0.178   | 0.320 0.240                      | 0.080               | 0.016 0.067   | 0.016 0.067             | 0.014 0.015                 | 48                          | 12.75       | 0.48   | 0.985 | 851 |
| 19.6           | 0.060 0.239   | 0.299 0.270                      | 0.029               | 0.014 0.015   | 0.014 0.015             | 0.014 0.015                 | 48                          | 12.75       | 0.48   | 0.985 | 851 |
| (A + B)        | 32.6          | 0.102 0.202                      | 0.304 0.263                      | 0.041 0.179   | 0.012 0.016             | 0.010 0.041                 | 80                          | 7.24        | 0.64   | 0.992 | 997 |
| 42.0           | 0.130 0.171   | 0.301 0.250                      | 0.051               | 0.009 0.061   | 0.009 0.061             | 0.009 0.061                 | 80                          | 7.24        | 0.64   | 0.992 | 997 |
| 19.6           | 0.058 0.230   | 0.288 0.233                      | 0.055               | 0.002 0.033   | 0.002 0.033             | 0.002 0.033                 | 60                          | 7.24        | 0.64   | 0.992 | 997 |
| (B + C)        | 32.6          | 0.099 0.200                      | 0.299 0.225                      | 0.074 0.303   | 0.020 0.054             | 0.018 0.073                 | 80                          | 20.00       | 0.41   | 0.999 | 999 |
| 42.0           | 0.135 0.181   | 0.316 0.225                      | 0.091               | 0.018 0.073   | 0.018 0.073             | 0.018 0.073                 | 80                          | 20.00       | 0.41   | 0.999 | 999 |
| 49.0           | 0.163 0.165   | 0.328 0.228                      | 0.100               | 0.016 0.084   | 0.016 0.084             | 0.016 0.084                 | 84                          | 20.00       | 0.41   | 0.999 | 999 |
| 19.6           | 0.065 0.230   | 0.295 0.260                      | 0.035               | 0.013 0.022   | 0.013 0.022             | 0.013 0.022                 | 62                          | 20.00       | 0.41   | 0.999 | 999 |
| (A + C)        | 32.6          | 0.110 0.226                      | 0.336 0.248                      | 0.088 0.178   | 0.013 0.075             | 0.011 0.087                 | 89                          | 17.80       | 0.43   | 0.960 | 862 |
| 42.0           | 0.152 0.187   | 0.339 0.241                      | 0.098               | 0.011 0.087   | 0.011 0.087             | 0.011 0.087                 | 89                          | 17.80       | 0.43   | 0.960 | 862 |
| 49.0           | 0.178 0.163   | 0.341 0.238                      | 0.103               | 0.010 0.093   | 0.010 0.093             | 0.010 0.093                 | 91                          | 17.80       | 0.43   | 0.960 | 862 |

* Upper punch displacement value
The constants $A_c$ and $x$ calculated using the least squares fits concern the physical reactivity of excipient particles characterized by the reduction in size due to compression and denoted as reduction tendency, RT, and the recovery and detachment index, detachment and recovery index (DRI), of the particles.

**DISCUSSION**

This study introduces a simple and reliable mathematical approach to determine DRI as a measure of powder compressibility. In this approach, there is no need to employ calibrated instrumented tabletting machines[3] and to deduce constant parameters of the being compressed powders[4,5] to measure its compressibility. The study also examined the correlations that might exist between DRI and the physical properties of the compressed tablets.

The wide size variation and the adequate flow properties of the powder materials employed in this investigation caused the segregation observed upon compression and therefore nonuniform tablet batches were produced. Formulations exhibiting continuous, uniform and controlled flow could be produced mixing excipients possessing glidant effect such as star-x[12] or MCC[13]. Contributing such excipients to formulations could minimize or diminish the interparticulate friction to a level favorable to uniform and continues flow and therefore uniform tablets could be produced.

Sugary excipients such as celutab possess high brittleness indices[14]. This excipient deforms under compression and generate fine particles which find its way to percolate and fill the spaces between large particles to decrease the voids. As compression process progresses the percolation process continues and results in producing compacts of low voids fraction.[4] This percolation process proceeds in a smaller degree with star-x due to its smaller brittleness index[14]. Due to its small brittleness index[14], MCC failed to generate new surfaces upon compression,[15] therefore the tables made with this excipient had small porosity fractions. Celutab/star-x blends produced the least porous tablets followed by MCC/star-x. On the other hand, celutab/MCC mix produced porous tablets, i.e., the compression behavior of MCC was not improved by mixing with celutab.

Excipients of high bonding particles such as celutab and star-x consolidate, deform and bond into compacts of high levels of crushing strength under small pressure. This is supported by the liquid film surface theory of bonding.[15] In addition, the high moisture content of these excipients play a vital role to promote particles bonding. It seems that the brittleness indices of these excipients had a little effect on particles bonding of and, therefore, compacts of enhanced mechanical properties were produced from these excipients. MCC particles were reported to show a little deformation and fusion under pressure.[13] Therefore, it was not surprising to compress porous compacts of low crushing loads from this excipient. Blends of celutab with other excipients produced tablets of enhanced crushing load levels properties.

Figure 1 shows the exponential decay of $\varepsilon$% of the studied batches fits the relation:

$$\%\varepsilon = \varepsilon_o e^{-k\varepsilon C}$$

where $\varepsilon$% represents the porosity fraction of the tablets made with no excipient (control batch) and $k_\varepsilon$ is a dimensionless parameter concerning the percolation of fine particles to fill the spaces between large particles during compression. It is the percolation index, PI, of a named excipient in a given tablet system. $k_\varepsilon$ values obtained for the tested excipients and their blends are given in Table 4. Excipients of highly bonding particles generated low $k_\varepsilon$ values.

It is seen in Figure 2 that the crushing loads, $H$, exponentially increased as $C$ increased in a given tablet system and the relationship:

$$H = H_0 e^{k^H C}$$

**Figure 1:** $\ln \varepsilon$ as a function of percent excipient concentration, C, for tablets made with (a) single and (b) binary blends of excipients, key: (a) ♦, MCC; ▲, star-x; and ■, celutab, (b) ◆, celutab/star-x (B + C); ♦, MCC/star-x; (A + C) and ■, MCC/celutab (A + B)
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Figure 2: ln H as a function of C for the tablets tested as in Figure 1

Table 4: The regressions of the expressions mentioned in the equations in the text

| Regression of | Formulation excipients |
|--------------|-------------------------|
| ln ε vs C    | A | B | C | A + B | B + C | A + C |
| intercept    | -2.09 | -1.55 | -1.90 | -1.38 | -1.33 | -1.11 |
| Slope, Pi, kₚ | -1.51 | -3.00 | -1.13 | -0.96 | -5.02 | -4.30 |
| Correlation coefficient, r | -0.93 | -0.93 | -0.97 | -0.87 | -0.94 | -0.97 |

| ln H vs C    | intercept | 1.40 | 1.19 | 1.29 | 1.90 | 1.89 | 2.12 |
| Slope, HCP | 0.76 | 1.90 | 1.83 | 1.04 | 1.02 | 0.87 |
| Correlation coefficient, r | 0.98 | 0.99 | 0.99 | 0.99 | 1.00 | 0.99 |

| ln F vs C    | intercept | 1.74 | 0.87 | 0.24 | 2.00 | 1.20 | -0.67 |
| Slope, RAI | -3.93 | -1.66 | -3.80 | -5.50 | -2.15 | -3.50 |
| Correlation coefficient, r | -0.98 | -0.95 | -0.97 | -0.98 | -0.95 | -1.00 |

| ln D vs C    | intercept, g min⁻¹ | 0.90 | 0.84 | 0.790 | 0.65 | 0.51 | 0.06 |
| Slope, DC | -0.68 | 2.03 | -3.300 | -6.50 | -6.70 | -0.31 |
| Correlation coefficient, r | -1.00 | 0.99 | -0.980 | -0.94 | -1.00 | -0.97 |

holds. \( H^0 \) and \( k_p \) stand for the crushing load of the control tablet batch and the hardness concentration profile, HCP, of an excipient in a batch. Table 3 shows that excipients of high bonding particles possessed high HCP values. Mixing of such excipients with excipients of poorly bonding particles yielded formulations of improved compressibility. It should be clear in mind the negative effect of brittleness on the crushing load of the produced compacts.

Figure 3 shows that friability, \( F \), correlates to C in a give batch by the relation:

\[
F = P^0 e^{-k_p C} 
\]  
(15)

where \( P^0 \) stands for the friability of the control tablet batch and \( k_p \) is the resistance to abrasion index, RAI, of the tablets. Table 3 shows that the excipient of particles of high bonding potentiality generated higher RAI.

Figure 4 shows that the disintegration time, \( D_r \), of the a tested tablet batch is generally excipient-type and concentration dependent factor. Star-x (starchy) and celutab (soluble) excipients produced fast disintegrating tablet. The incorporation of such excipients in formulation shortened the disintegration time. Figure 4 also shows that the disintegration rate constant, \( D, \) g min⁻¹, is correlated to C in a given batch by the relation:

\[
D = A_d e^{k_d C}. 
\]  
(16)

The constants, \( A_d \) and \( k_d \) given in Table 4 concern the \( D \) of the control batch and a parameter indicative of the disintegration capacity, DC, of the excipient in the batch, respectively. Star-x possessed the highest DC value [Table 4]. DC of MCC could be improved by contributing an excipient of high DC in formulation.

Figure 5 represents the relationship existing between \( \Delta L_x \) and C for the studied tablet batches. Table 4 clearly shows...
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Figure 3: ln F as a function of C for the tablets tested as in Figure 1

Figure 4: ln D as a function of C for the tablets tested as in Figure 1. Key as in Figure 1

Figure 5: ln ΔΛ vs ln C plot for the tablets tested as in Figure 1. Key as in Figure 1

Figure 6: PI, HPC, RAI, and DC each as a function of DRI for the tested tablets
that cellulose and starch excipients possessed higher RT values. Their particles could absorb the compression pressure and deform where the particles of the brittle excipients such as celutab did not show such physical reactivity toward the compression pressure. The RT of such brittle materials would be improved by mixing with excipients of higher RT values. However, celutab and star-x, in this order, generated the least DRI value, i.e., they are more compressible. This is supported by the liquid surface film theory of bonding.[14] Higher DRI value is recorded for MCC molecules, i.e., it is comparatively less compressible as explained above [Figure 6].

CONCLUSIONS

Tablet weight and dimensions could be employed to measure the compressibility of the excipients in direct compression tablets. This simple and reliable approach is not limited to evaluate powder compressibility in direct compression tablet systems. It can be successfully employed to measure the binding properties of binders in wet granulation tablets. The introduced approach however failed to account for the energy consumed in compressing powders into tablets.

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REFERENCES

1. Mani S, Tabil LG, Sokhansanj S. Evaluation of compaction equations applied to four mass species. Canad. Biosyst Eng 2004;46:355-61.
2. Penny PJ. Compaction equations: A comparison of the Heckel and Kawakita equations. Powder Technol 2002;127:162-72.
3. Heckel RW. An analysis of powder compaction phenomena. Trans Metallurgal Soc AIME 1961;221:1001-8.
4. Kawakita K, Lüdde KH. Some considerations on powder compression equations. Powder Technol 1971;4:51-68.
5. Cooper AR, Eaton LE. Compaction behavior of several ceramic powders. J Am Ceram Soc 1962;45:97-101.
6. Shapiro I. Compaction of powders X. Development of a general compaction equation. advances in powder metallurgy and particulate materials Vol,3, Modeling, design and computational methods Nashville, Tennessee, USA, 1993;3:229-43.
7. Sonnegaard JM. Investigation of a new mathematical model for compression of pharmaceutical powders. Europ. J Pharm.&Biopharm. 2001;14:194-57.
8. Panelli R, Filho FA. A study of a new phenomenological compacting equation. Powder Technol 2001;114:255-61.
9. Comoglu T. An overview of compaction equations. J Fac Pharm 2007;36:123-33.
10. Aly SAS. New approach for evaluating the compresional behaviours of pharmaceutical powders 2. Surface area of formulation excipients in tablet systems containing a non compressible component. STP Pharma Sci 1994;4:414-20.
11. Chukwu A. Studies on detarium microparium gum I. comparative evaluation of a binder in tablets containing tartrazine dye STP Pharma Sci. 1992;2:463-8.
12. Manudhane KS, Contractor AM, Kim HY, Shangraw RF. Tableting Properties of Directly Compressible Starch. J Pharm Sci 1969;58: 616-20.
13. Richman MD, Fox CD, Shangraw RF. Preparation and stability of glyceryl trinitrite sublingual tablets prepared by direct compression. J Pharm Sci 1965;54:447-51.
14. Rudnic EM, Schwartz JB. Solid dosage form. In: Gennaro AR, editor. Remington: The science and practice of pharmacy 20th ed. Philadelphia: Philadelphia College of Pharmacy and Science; 2000. p. 883.
15. Parrott EL. The process of compression. In: Lieberman HA, Lachman L, Schwartz JB, editors. Pharmaceutical dosage forms: Tablets Vol. 2. New York: Marcel Dekker;1990. p. 210-41.

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