Characterization of microcrystalline celluloses by means of the parameters of a three-exponential compression equation

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Received 19 Juny / Accepted 30 July 2008

SUMMARY

Characterization of microcrystalline celluloses by means of the parameters of a three-exponential compression equation

The study compares microcrystalline celluloses by means of the parameters of the three-exponential equation $V/V_0 = A_1^*exp(-P/t_1) + A_2^*exp(-P/t_2) + A_3^*exp(-P/t_3) + y_0$ [1)]. The process of compression, according to this equation, takes place in three stages: in the stage of reduction of interparticular pores, reduction of intraparticular pores, and in the stage of reduction of the solid substance without pores. The classic theory of compression is based on the fact that the individual processes take place within the ranges of concrete compression pressures. According to the new equations, the processes under evaluation take place concurrently within the whole range of compression pressures employed. The paper studied four microcrystalline celluloses, Avicels PH 102, PH 103, PH 105, and PH 301. These excipients differ in sizes and shapes of particles, density, and content of humidity. The evaluations included the sizes of reductions A_R, sizes of energies E_A, and "half-pressures" P_H. The results of the study show that with diminishing particles of microcrystalline celluloses energies E_A are decreased and "half-pressures" are simultaneously increased. Best compressibility was found in Avicel PH 102 with the value of the "half-pressures" of 119.954 MPa and the worst in Avicel PH 301 with the value of the "half-pressures" of 151.449 MPa.

Key words: three-exponential equations of compression – microcrystalline celluloses – theory of compression of tablets

Čes. slov. Farm., 2008; 57, 165–169

SOUHRN

Charakterizace mikrokrystalických celulos parametry trojexponenciální rovnice lisování

V práci jsou mikrokrystalické celulosy porovnány pomocí parametrů trojexponencinální rovnice $V/V_0 = A_1^*exp(-P/t_1) + A_2^*exp(-P/t_2) + A_3^*exp(-P/t_3) + y_0$ [1)]. Proces lisování pomocí této rovnice probíhá ve třech fázích, ve fázi redukce interpartikulárních pórů, redukce intrapartikulárních pórů a ve fázi redukce tuhé látky bez pórů. Klasická teorie lisování vychází ze skutečnosti, že jednotlivé procesy probíhají v rozmezí konkrétních lisovacích tlaků. Podle nových rovnic hodnocené procesy probíhají souběžně v celém použitém rozsahu lisovacích tlaků. V práci byly studovány čtyři mikrokrystalické celulosy, Avicely PH 102, PH 103, PH 105 a PH 301. Tyto pomocné látky se liší velikostí a tvarem částic, hustotou a obsahem vlhkosti. Byly hodnoceny velikosti redukcí A_R, velikosti energií E_A a „půltlaky" P_H. Z výsledků práce vyplynulo, že se zmenšováním částic mikrokrystalických celulos se energie E_A snižují, současně se „půltlaky" zvyšují. Nejlepší lisovatelnost má Avicel PH 102 s hodnotou „půltlaku" 119,954 MPa a nejhorší lisovatelnost Avicel PH 301 s hodnotou „půltlaku" 151,449 MPa.

Klíčová slova: trojexponenciální rovnice lisování – mikrokrystalické celulosy – teorie lisování tablet

Čes. slov. Farm., 2008; 57, 165–169

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Introduction

The compression process is characterized by the compression equation. It expresses the effect of compression pressure on the changes in the height, volume, or density of the tablet. At present the research of tablets uses three models of compression equations. The first and oldest model is the expression of the compression process by a straight-line equation. This model is represented by the equation according to Walker [2] and Balshin [3]. The second model expresses the compression process by the hyperbolic equation, an example being the equation according to Kawakita and Lüdde [4]. The third model is the expression of the compression process by means of a two-exponential equation. This method was employed by Cooper an Eaton [5]. This equation was created for the compression of ceramic materials. It has been found that the above-mentioned equation describes the compression process of crystalline pharmaceutical excipients, but it is not suitable for polymeric excipients. The three-exponential equation is more suitable for these substances:

$$\frac{V}{V_0} = A_1 e^{-\frac{1}{t_1}P} + A_2 e^{-\frac{1}{t_2}P} + A_3 e^{-\frac{1}{t_3}P} + y_0$$

V_0 is the initial volume of the tableting material which is being compressed, V, the volume of the tableting material at a given compression pressure. The parameter y_0 represents the volume of the compact V_∞ at the endless compression pressure. P are the compression pressures. Parameter A_1 represents the reduction of interparticular pores, parameter A_2 the reduction of intraparticular pores, and parameter A_3 the reduction of the solid substance without pores. Parameters $1/t_{1–3}$ are the velocity constants of the appropriate reductions of volumes, out of which other parameters $P_{H1–3}$ are calculated. These parameters express the compression pressures, up to which one half of the reduction of interparticular pores, intraparticular pores, or the reduction of the solid substance without pores take place. The new parameters $E_{1–3}$ express the energy consumed to materialize the given reductions of the volume. The parameters $E_{A1–3}$ express the energy related to a unit of parameter A, i.e. a unit of the reduction of volumes in individual processes.

The study included the microcrystalline celluloses Avicel PH 102, PH 103, PH 105 a PH 301.

EXPERIMENTAL PART

Raw materials employed

The model dry binders for direct compression were the microcrystalline celluloses Avicel PH102, PH 103, PH 105, PH 301 manufactured by the firm FMC Corporation, Belgium. All materials were Ph. Eur. grade and used as purchased without preconditioning.

Preparation of tablets

Tablets of the diameter of 13 mm and weight of 500 mg were compressed in a compression preparation (Adamus HT, Machine Factory Group, Szczecin, Poland) in an apparatus for testing tensile and compression strengths T1-FRO 50 (Zwick GmbH, Ulm, Germany). Tablets were compressed using the following adjustment of the apparatus: distance of the punches 115 mm, standard strength 42000 N, unloading of the cycle 10 mm, velocity of the cycle 2 mm/s, pre-loading 2N, and pre-loading velocity 2 mm/s at the following compression forces: 50N, 100N, 150N, 200N, 250N, 300N, 350N, 400N, 450N, 500N, 750N, 1000N, 1500N, 2000N, 2500N, 3000N, 3500N, 4000N, 4500N, 5000N, 5500N, 6000N, 6500N, 7000N, 7500N, 8000N, 8500N, 9000N ,9500N, 10000N, 11000N, 12000N, 13000N, 14000N, 15000N, 16000N, 17000N, 18000N, 19000N, 20000N, 22000N, 24000N, 26000N, 28000N, 30000N, 32000N, 34000N, 36000N, 38000N, 40000N. In each of the compression forces 20 tablets were evaluated.

Evaluation of the parameter of the compression process

The following three-exponential equation of compression was employed to calculate the parameters of the compression process:

$$\frac{V}{V_0} = A_1 e^{-\frac{1}{t_1}P} + A_2 e^{-\frac{1}{t_2}P} + A_3 e^{-\frac{1}{t_3}P} + y_0$$

The parameters of the above-mentioned equations were calculated by means of the programme OriginPro 7.5 by the function ExpDec3. The sum of parameters $A_{1–3}$ and y_0 represents the total volume of the compressed material at zero compression pressure. Parameter y_0 represents the volume of the solid substance at endlessly large compression pressure. For a better comparison of the individual excipients, the sum of the reductions A_1, A_2 and A_3 was converted to the value of 1.0, thus obtaining parameters $A_{R1,}$ A_{R2} and A_{R3}. Volume changes in all tested substances thus ranged between 0 and 1. After this modification, the following equation was obtained:

$$\frac{V}{V_0} = A_{R1} e^{-\frac{1}{t_1}P} + A_{R2} e^{-\frac{1}{t_2}P} + A_{R3} e^{-\frac{1}{t_3}P}$$

Values $t_{1,}$ $t_{2,}$ t_3 represent changes in compression pressure which cause a change in the volume V/V_0 to a certain value. These parameters were employed to calculate the "half-pressures" and the energy of compression.

Values $t_{1,}$ $t_{2,}$ t_3 served to calculate parameters P_{H1}, P_{H2}, P_{H3}. These new parameters, "half-pressures", express the compression pressures at which reductions of interparticular pores, intraparticular pores, or reduction of a solid substance without pores to one half take place.

New parameters were calculated according to the following equations:

$$V(t) = Ae^{\frac{-t}{t_i}}$$

$$Ae^{\frac{-t+\Delta t}{t_i}} = \frac{Ae}{2}^{\frac{-t}{t_i}}$$

$$\Delta t = t\ln 2$$

The following relations were employed to calculate the percentages of the energies of individual processes from parameters t_1, t_2, t_3:

$$dV = V'(P)dP$$
$$dE = P.V'(P)dP$$

This results in the conclusion that there is a dependence of the travel on force, but because the resultant energy is expressed in percents and calculated from relations (see the relation shown below), the percentual representation of energy for each process is identical also as far as the dependence of the ratio volume V/V_0 on compression pressure P is concerned.

The calculation of the percentage of energy for each process uses the equation:

$$E_i = \frac{A_i t_i}{\Sigma A_i t_i} \%$$

Energies $E_{A\ 1-3}$ related to reductions of volumes were calculated according to the equation:

$$E_{A_i} = \left(\frac{E_i}{A_i}\right) [\%]$$

RESULTS AND DISCUSSION

Due to their good compressibility, microcrystalline celluloses are widely used excipients in the capacity of a filler for direct compression or a binder for most granulation [6].

Cellulose fibres are composed of a large number of hollow microfibres. Two segments are recognized in these microfibres. There is a paracrystalline region, which is amorphous mass of cellulose chains, and a crystalline region, which is composed of solid bundles of cellulose chains in a solid linear arrangement. In their manufacture, as a result of acid hydrolysis, the amorphous region is partly removed to the detriment of the crystalline region [7].

The binding properties are based on the hydrogen bridges between hydroxyl groups of the material. By means of compression pressure, the particles get into a very close contact and thanks to it these bonds develop very readily and on a large area. This is the reason for very good compression properties of microcrystalline cellulose and its good strength. Compression properties of microcrystalline cellulose are also influenced by humidity. The largest amount of water molecules is contained in the porous structure of microcrystalline cellulose and a certain share of moisture plays an important role in the formation of hydrogen bonds in these materials [8].

Four microcrystalline celluloses were evaluated in the study. The obtained results are presented in Tables 1–3 and Figs. 1–5. The principal microcrystalline cellulose for the evaluation was Avicel PH 102. It possesses an

Tab. 1. Comparison of densities in the excipients under study (abbreviations of densities are explained in the paper)

Excipients	D_{MAX} (g/cm^3)	D_{40kN} (g/cm^3)
Avicel PH 102	4.7562	2.6987
Avicel PH 103	4.9305	2.8562
Avicel PH 105	5.4603	2.8406
Avicel PH 301	6.5079	2.8805

Tab. 2. Parameters A_{R1-3} and E_{1-3} in the excipients under study (abbreviations of parameters of compression are explained in the paper)

Excipients	A_{R1}	A_{R2}	A_{R3}	E_1 (%)	E_2 (%)	E_3 (%)
Avicel PH 102	0.19433	0.44423	0.36143	0.62112	9.2889	90.08997
Avicel PH 103	0.19132	0.428	0.38068	0.54727	8.79587	90.65686
Avicel PH 105	0.18911	0.34593	0.46496	0.33113	6.32171	93.34716
Avicel PH 301	0.16322	0.36742	0.46936	0.35827	7.11988	92.52185

Tab. 3. Parameters E_{A1-3} and P_{H1-3} in the excipients under study (abbreviations of parameters of compression are explained in the paper)

Excipients	E_{A1} (%)	E_{A2} (%)	E_{A3}(%)	P_{H1} (MPa)	P_{H2} (MPa)	P_{H3} (MPa)
Avicel PH 102	0.03197	0.20910	2.49266	1.53875	10.06267	119.95434
Avicel PH 103	0.02860	0.20550	2.38169	1.53051	10.99600	127.43669
Avicel PH 105	0.01751	0.18272	2.00784	1.19852	12.50938	137.48639
Avicel PH 301	0.02195	0.19378	1.97128	1.68669	14.88778	151.44941

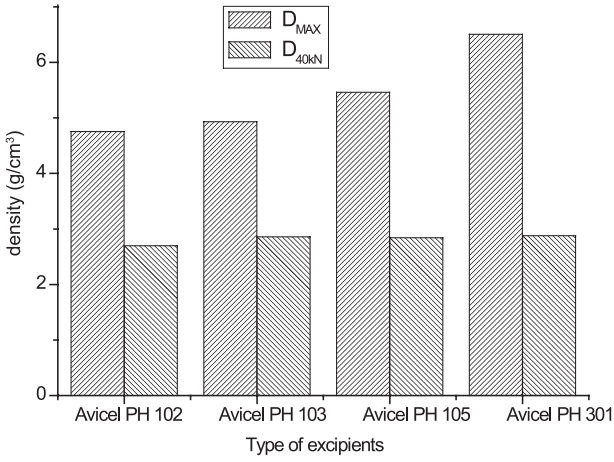

Fig. 1. Densities in the excipients under study (abbreviations of densities are explained in the paper)

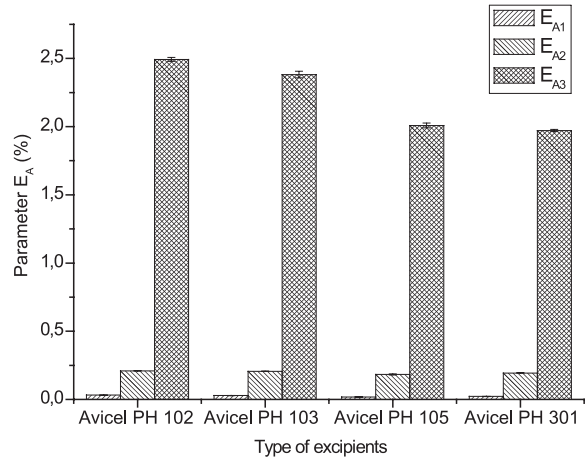

Fig 4. Parameters E_{A1-3} in the excipients under study (all columns displayed means of n = 20 with 1s error bars)

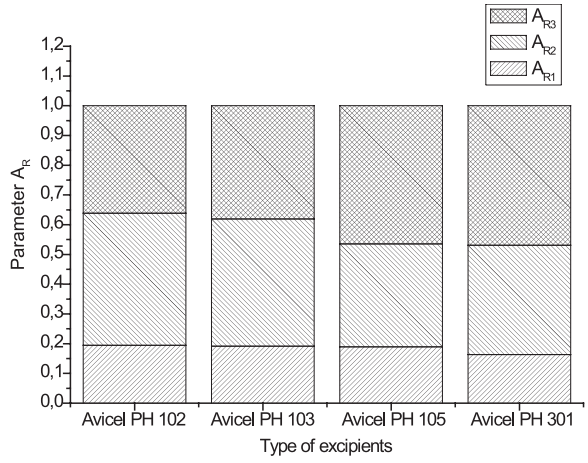

Fig. 2. Parameters A_{R1-3} in the excipients under study

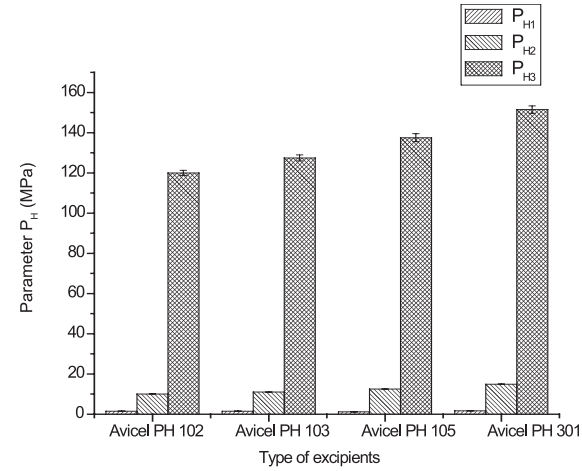

Fig. 5. Parameters P_{H1-3} in the excipients under study (all columns displayed means of n = 20 with 1s error bars)

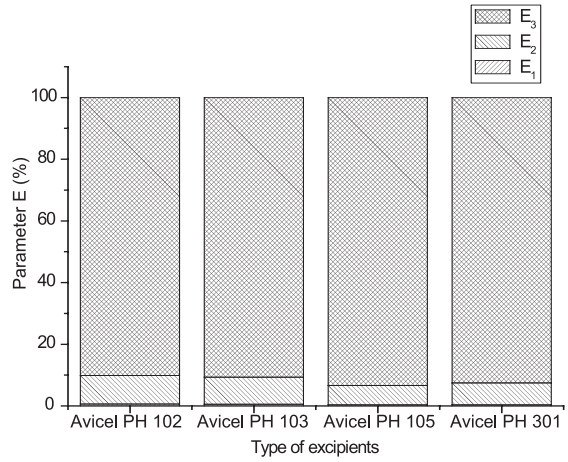

Fig. 3. Parameters E_{1-3} in the excipients under study (all columns displayed means of n = 20 with 1s error bars)

average particle size of 100 μm, humidity 5%, and density D_{MAX} 4.756 g/cm^3. This substance possesses the parameters A_{R1} 0.194, A_{R2} 0.444 and A_{R3} 0.361 and E_{A1} 0.032%, E_{A2} 0.209%, E_{A3} 2.492% and the "half-pressures" P_{H1} 1.539 MPa, P_{H2} 10.063 MPa and P_{H3} 119.954 MPa.

Avicels PH 103 and PH 105 in comparison with Avicel PH 102 possess an approximately identical density D_{MAX}, but they differ in the average particle size. Avicel PH 103 has the size of 50 μm and Avicel PH 105 20 μm. Reductions of interparticular pores between three Avicels under comparison are approximately identical. However, the evaluation of other two parameters is different. With increasing particle size the reduction of intraparticular particles is increased and at the same time the reduction of the solid substance without pores is decreased. The parameters of reductions of volumes are related directly to particle size and thus the pertinent relations after poring of the excipient into the matrix. With decreasing particle size, energies E_A are decreased in all three stages of the compression process. It seems that the bonds between surface chains of cellulose consume less energy than those between the chains within the particles. The final criterion of evaluation is "half-pressures". In the stage of reduction of interparticular pores, "half-pressures" in all three microcrystalline celluloses are approximately identical in the range from 1.199 to 1.538 MPa. But in two subsequent stages the "half-pressures" are increased with

the decreasing particle size, in the stage of reduction of intraparticular pores in the range from 10.063 to 12.509 MPa and in the stage of reduction of the solid substance without pores in the range from 119.954 to 137.437 MPa. It means that with the diminishment of the particles of microcrystalline celluloses energies E_A are decreased with a concurrent increase in the "half-pressure" values.

Another microcrystalline cellulose under evaluation is Avicel PH 301. It differs from Avicel PH 102 in a substantially higher density D_{MAX} at the level of 6.507 g/cm^3. Its particle size is 50 μm and humidity content, 5%. In contrast to Avicel PH 102, it has lower values of reductions of both interparticular and intraparticular pores, which may be caused by its particle size. On the other hand, the reduction of the solid substance without pores is higher, caused probably also by a higher density. Energies E_A in Avicel PH 301, in contrast to Avicel PH 102, are in all three stages of compression process lower and "half-pressures" higher.

An important criterion of evaluation is the values of "half-pressures". Lower values in the stage of reduction of the solid substance without pores mean better compressibility. From the given aspect, the best compressibility is found in Avicel PH 102 with the "half-pressure" value of 119.954 MPa and the worst compressibility in Avicel PH 301 with the "half-pressure" value of 151.449 MPa.

The study was financially supported by research project MSM 0021620822.

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