to 4500 Kg. is given in Table VI. It can be seen from the data in this table that more work is expended on the potassium chloride crystals up to 1500 Kg., while for potassium citrate more work is expended from 1500 to 4500 Kg. This would indicate that the potassium chloride crystals are undergoing greater deformation and compaction at the lower load range while the reverse is true for potassium citrate.

SUMMARY AND CONCLUSION

A description has been presented of a modified Instron physical testing instrument which can be used to obtain a quantitative measure of the compressibility of pharmaceutical solids. Preliminary information is given for potassium chloride and potassium citrate crystals and granulations of these salts which can be summarized as follows.

1. Potassium chloride was found to deform at lower compression loads than potassium citrate.

2. Modifying the two salts by granulating with materials commonly used in tablet technology indicated that the inherent compression properties of the salts predominated. The granulating agents employed were water, acacia, starch paste, and polyvinylpyrrolidone.

3. A linear relationship was found for log load *versus* deformation for both salts at load levels up to 300 Kg. However, at higher loads, this linear relationship did not hold true.

4. In order to permit a measure of the relative compressibility of the materials at high load levels, a computer program was prepared to determine the quadratic equation best fitting the experimental data which were subsequently used to obtain the compression slopes at each load by calculating the derivative.

5. The relationship between compression slope and load can be used to determine the load range at which maximum deformation of the solid bed is taking place.

6. The work expended at different loads can also be used to determine the load range of maximum deformation.

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Powder Flow Studies I

Instrumentation and Applications

By GERALD GOLD, RONALD N. DUVALL, and BLAZE T. PALERMO

Several methods have been used to evaluate the flow properties of pharmaceutical formulations. Although these methods give reproducible results, they often measure different factors. Consequently, it is difficult to interpret the data, and it is debatable whether correlation with actual flow of material is possible. A new approach to the measurement of powder flow is presented and involves measurement of the weight of powder per unit time flowing through a hopper orifice. The instrument, a recording powder flowometer, consists of a hopper, strain gauge balance, and recorder. The flow rate can be calculated from the recorder tracing, and in addition, the tracing serves to characterize the flow qualities of a formulation. Various sized hopper orifices with or without vibration can be used. By incorporation of an ionostat into the instrument, the static charge may also be measured concurrently with the flow rate.

FLOW PROPERTIES of pharmaceutical formulations are extremely important to the industrial pharmacist. Increasing complex manufacturing techniques and modern dosage forms require a more thorough and basic understanding of the science and technology of small particles. In tablet and capsule manufacturing, considerable effort is directed toward obtaining and improving free flowing powders and granulations. Recent compendia standards and law enforce-

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ment activity relative to intertablet dosage variation have further emphasized the problem. Research in this area has been hindered by the lack of suitable instrumentation, and, until fairly recently, flow properties were often evaluated empirically.

Methods currently in use in an attempt to evaluate powder flow include measurements of the angle of repose or angle of spatula and timed delivery from an orifice. The angle of repose is a measure of the static coefficient of interparticular friction, and is the maximum angle possible between the surface of a pile and the horizontal plane. The angle of spatula is also a measure of interparticular friction. In this method, a spatula is inserted parallel to the bottom of the container and then lifted straight up and out of the material, thereby creating an angle to the horizontal (1). Timed delivery through an orifice has also been used to evaluate flow of materials, with either the volume or weight of powder flowing through the orifice in a specified time period measured (2). Munzel (3) also utilized this principle with a modified Emix powder dispenser. Although, separately, these three methods give reproducible comparative results, they have no specific relation to each other, and are not necessarily influenced by the same factors.

Powder flow problems encountered in this laboratory could not be satisfactorily resolved with the various methods described above. Consequently, an instrumented approach to the problem has been developed and appears to be more closely related to actual flow of materials under production conditions. A recorder tracing of the weight of the powder flowing through a hopper *versus* time is obtained. The tracing serves to illustrate graphically variations or fluctuations in flow patterns. The flow rate through a given hopper orifice with or without vibration is easily calculated from the tracing and, in addition, an ionostat can be used to measure the static charge concurrently with the flow rate. This report describes the recording powder flowometer which should lend itself to basic studies of the flow of powdered or granular materials. An example is presented to illustrate the usefulness of the instrument in identifying the ingredients in a complex formulation which adversely influence flow and in confirming an improved flow of the reformulated material.

EXPERIMENTAL

Materials.—Commercially available materials of either U.S.P., N.F., or pharmaceutical grade were used. The following materials were powders: anhydrous dicalcium phosphate, magnesium stearate, niacinamide, riboflavin, and thiamine. The following were crystalline: ascorbic acid, aspirin, anhydrous citric acid, sodium ascorbate, and tartaric acid. The remaining materials were processed granules.

Description of the Recording Powder Flowometer.—The instrument consisted basically of a strain gauge balance and recorder along with various hoppers. The hoppers were stainless steel, conical in shape, and measured 20 cm. top diameter by 30 cm. in length with orifice diameters of 8.0, 10.0, and 15.0 mm. In order to study poorly flowing materials, a vibrolator[1] was attached to the 10.0-mm. hopper and connected by means of rubber tubing through a pressure regulator[2] to a laboratory air jet. The pressure regulator can be set at any air pressure depending on the amount of vibration desired. In those experiments requiring vibration, a setting of 10 lb./sq. in. was used. The strain gauge balance is shown schematically in Fig. 1. The receiving platform (B) was positioned 11 cm. directly beneath the hopper orifice. This platform was supported by bar (C), the upper of two brass bars mounted horizontally to the wood support. The lower horizontal bar (D), fastened at one end, bends when weight is placed on the platform. Two strain gauges[3] were fastened to this bar. Within the enclosed area (A) were the resistors, resistor controls, and the circuit switch. The electrical diagram indicating the bridge circuit, voltage regulator, and strip chart recorder is also shown in Fig. 1. Voltage regulation was accomplished with a transistorized power supply model 1020[4] set at 8 v. The Brown electronik[5] recorder has a 0–2-mv. range for 25.4 cm. full scale and a chart speed of 0.33 cm./sec.

Calibration of the Instrument.—Due to the change in resistance of the deformed strain gauges when powder flows through the hopper onto the platform, a voltage difference results in the two arms of the bridge circuit. The magnitude of this change in potential, indicated by the recorder, was found to be directly proportional to the weight on the strain gauge balance. The recorder response was calibrated by adding weights to the platform and noting the millivolt response. The linear relationship between recorder response and weight is shown in Fig. 2. The weight of material that has flowed through the hopper at any given time could be ascertained from the calibration curve. In this study, however, an equation based on the method of least squares was used to relate recorder response to weight in grams.

Measurement of Static Charge.—Static charge and flow rate can be measured concurrently if an ionostat described in a previous communication from this laboratory (4) is used and the platform of the strain gauge balance replaces the helipath stand.

RESULTS AND DISCUSSION

Typical results obtained with various materials having different flow rates are illustrated in Fig. 3.

[1] Model UCV-6, Martin Engineering Co., Neponset, Ill.
[2] C. A. Norgren Co., Littleton, Colo.
[3] Series SR4, type C-5, Baldwin-Lima-Hamilton Electronics, Waltham, Mass.
[4] Electronic Instrument Co., Inc., Flushing, N. Y.
[5] Honeywell, Inc., Philadelphia, Pa.

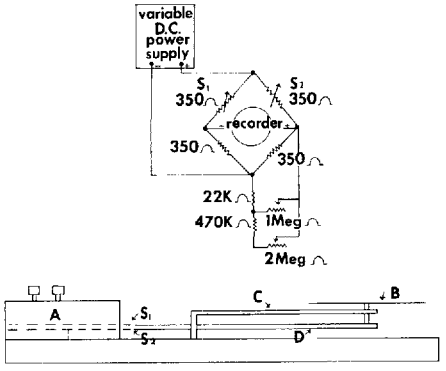

Fig. 1.—Strain gauge balance and electrical diagram.

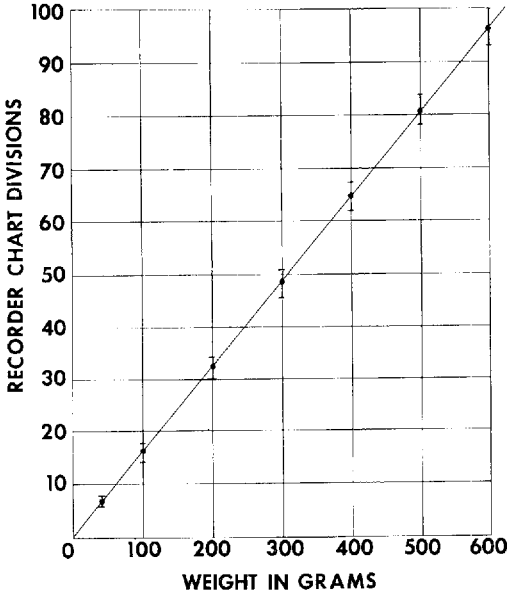

Fig. 2.—Calibration curve relating weight in grams to recorder response. The vertical bracketed lines represent 95% confidence limits.

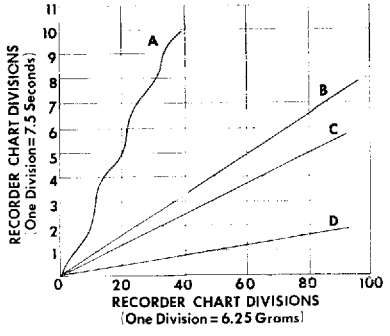

Fig. 3.—Flowometer recording of selected materials. Key: A, dicalcium phosphate anhydrous powder; B, calcium sulfate, dihydrate granulation; C, 20-mesh aspirin crystals; D, 18–25 mesh glass beads.

TABLE I.—FLOW RATE[a] AND CORRESPONDING STANDARD DEVIATION[b] OF SELECTED MATERIALS

Material	Flow Rate, Gm./sec.	S.D.
Glass beads, 18–25 mesh	42.57	0.20
$CaSO_4$ granulation	8.42	0.48
Aspirin crystals	11.17	0.70
Anhydrous $CaHPO_4$[c]	2.72	0.37

[a] 10-mm. diameter hopper orifice. [b] Based on nine determinations. [c] Using vibrator at 10 lb./sq. in.

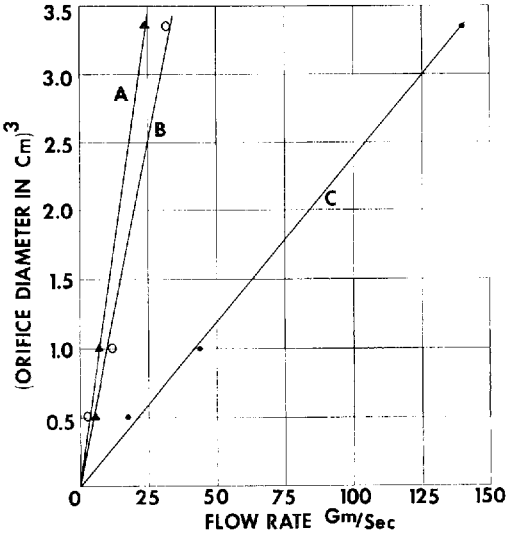

Fig. 4.—Relationship of flow rate to hopper orifice diameter cubed. Key: A, calcium sulfate dihydrate granulation; B, 10% starch granulated aspirin; C, 18–25 mesh glass beads.

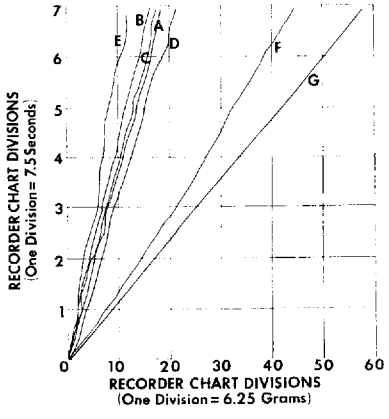

Fig. 5.—Flowometer recording of chewable hexavitamin tablet formulations. Key: A, original formula; the following ingredients were omitted from the original formula: B, magnesium stearate; C, thiamine; D, riboflavin; E, sodium ascorbate; F, niacinamide. Formula G was the reformulated product.

Glass beads, 18–25 mesh, a calcium sulfate granulation, aspirin crystals, and anhydrous dicalcium phosphate powder were used in order to ascertain precision of the instrument over a broad range of flow rates. Flow rates and corresponding standard deviations are shown in Table I.

The results indicate that the instrument is capable of monitoring flow of materials flowing at widely divergent flow rates and of giving good reproducibility. The recorder tracing provides continuous data on such flow with time, a major advantage of this instrument. Fluctuating or irregularly flowing materials can be readily identified. The pulsating character shown by the dicalcium phosphate powder represents alternating periods of flooding and starving. From Fig. 3, it can also be noted that the relative magnitude of the flooding may be estimated from the amplitude of the pulse pattern. This could prove valuable in solving problems relative to tablet weight variation.

The instrument appears to be applicable to basic studies in powder flow. The relationship originally established by Ketchum (5) indicated that the flow rate is directly proportional to the product of a constant, the density of the material, and the cube of the diameter of the orifice. This proved to be an oversimplification, primarily because other factors which affect the rate of discharge were not included (6). However, Fig. 4, although presented only to indicate a potential use for the instrument, does seem to show this relationship between the cube of the orifice diameter and flow rate.

Application of the instrument as an aid in solving flow problems either during the developmental stage of a new product or during production of an existing product appears promising also. To illustrate this point, chewable hexavitamin tablet N.F. formulations containing coated niacinamide, riboflavin, and thiamine, together with fine granular sodium ascorbate, magnesium stearate powder, granules of vitamins A and D, and mannitol were studied. The powder formulation has poor flow properties as illustrated by tracing A in Fig. 5. To analyze the powder mixture for the effect of individual ingredients on flow, five formulations in which a different ingredient was excluded from each were prepared. There appeared to be no significant differences in the flow patterns of the complete formula and of those formulations without either magnesium stearate, thiamine, or riboflavin. The formulation in which sodium ascorbate was omitted, tracing E, had a slower flow rate than the complete formula, indicating that this ingredient had a beneficial effect on the flow rate. When niacinamide was omitted from the formula, recording F, the material had a significantly faster flow rate, thus identifying niacinamide as that ingredient primarily responsible for the poor flow of the original formula. The product was then reformulated with a granulated niacinamide and the resulting formulation, tracing G, showed a marked improvement in flow rate. This example indicates the relative ease by which a poorly flowing formulation may be analyzed and improved through the use of this instrumented approach to the problem. This would be a formidable problem if approached by existing methods of flow evaluation.

The relationship of static charge to flow rate was studied by means of the flowometer modified with an ionostat. Flow rates and static charges of selected organic acids are listed in Table II. The results obtained with two different hopper orifices are the averages of nine determinations. The static charge, read directly from the ionostat, represents the maximum charge resulting from the flow of 500 Gm. of material. Although presented only to illustrate another potential application of the apparatus, it is interesting to note that the increase in flow rate from the larger orifice (15.0 mm.) effected an increase in static charge.

TABLE II.—FLOW RATES AND STATIC CHARGES OF SELECTED ORGANIC ACIDS AS OBTAINED WITH DIFFERENT HOPPER ORIFICES

	Orifice Diam., 8.0 mm.		Orifice Diam., 15.0 mm.	
	Flow Rate, Gm./sec.	Static Charge, −v./cm.	Flow Rate, Gm./sec.	Static Charge, −v./cm.
Aspirin	4.77	239	37.77	600
Ascorbic acid	4.41	472	36.11	744
Citric acid, anhyd.	3.77	533	44.22	1039
Tartaric acid	5.99	1306	49.37	2289

SUMMARY

A new instrumented approach applicable to the analysis of flow properties of powdered or granular materials has been described. The instrument, a recording powder flowometer, consists basically of various hoppers with or without vibration, a strain gauge balance, and a recorder. A major advantage of the apparatus is the recorder tracing from which the flow rate can be calculated and from which fluctuating or inconsistently flowing materials can be readily detected. In addition, incorporation of an ionostat into the flowometer permits simultaneous measurement of the static charge with the flow rate.

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