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Note

The effect of particle size on the heat of immersion of microcrystalline cellulose

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Summary

The effect of particle size on the heat of immersion of microcrystalline cellulose (Avicel) has been measured using microcalorimetry. Curves of heat of immersion against moisture content for all four particle sizes were superimposable when the data were expressed on a weight basis but when expressed on a surface area basis, the data for the smallest particle size were consistently lower. Reasons for this anomaly have been hypothesised.

The phenomenon of the evolution of heat when an insoluble, finely divided solid is immersed in a liquid has been known since the early nineteenth century (Pouillet, 1822). However it was not until a century later that detailed studies began (Boyd and Harkins, 1942a,b) since when it has been used to characterise a wide range of materials such as the inorganic fillers (e.g., barium sulphate), silicas, aluminas, pigments (e.g., iron oxide), opacifiers (e.g., titanium oxide) and polymers (e.g., PTFE) (see review by Zettlemoyer, 1965). Recently in pharmaceutical technology the technique has been used not only to characterise a number of fillers and pigments used in film coating (Gibson et al., 1988) but also to investigate source variation in microcrystalline cellulose (Parker and Rowe, 1991; Parker et al., 1992; Landin et al., 1993a,b) the latter being based on work by Hollenbeck et al. (1978).

A valuable aspect of the heat of immersion is that it is related to the interfacial surface energy. However, proof that the heat of immersion is caused by a change in the interfacial energy alone can only be obtained if the measured heat change is directly proportional to both the amount and surface area of the test material (Boyd and Harkins, 1942a). To date no detailed experiments of the effect of surface area have been performed on microcrystalline cellulose. The aim of this work is to remedy the situation.

Microcrystalline cellulose (Avicel, FMC Corp., Cork, Ireland) was obtained in four particle sizes (Table 1). Surface areas were determined using the BET method of nitrogen adsorption after degassing under vacuum at 70°C for 24 h. X-ray powder diffraction measured using monochromatic Cu Kα radiation at a scanning rate of 0.25° 2θ over the range 4–50° 2θ (model D5000,

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TABLE 1

Particle size / surface area data on materials used

Material	Particle size (μm) [a]	Surface area (m^2 g^{-1})
Avicel PH200	200	1.27
Avicel PH102	100	1.15
Avicel PH101	50	1.21
Avicel PH105	20	2.02

[a] Manufacturer's literature.

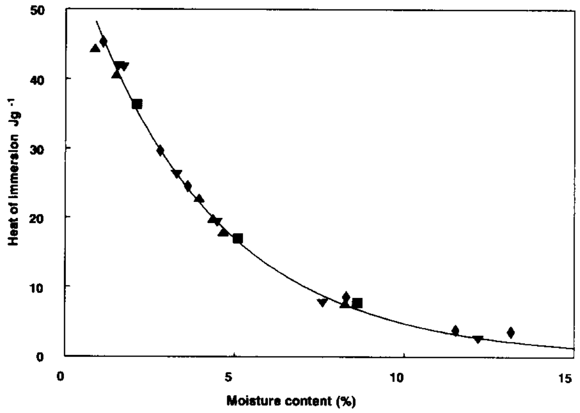

Fig. 1. Comparison of data for the heats of immersion against moisture content for Avicel PH101. Data from (■) this work; (▲) Parker and Rowe (1991); (▼) Parker et al. (1992); (◆) Landin et al. (1993b).

Siemens, Germany) gave identical spectra for all four materials with no detectable differences in crystallinity.

Immersion calorimetry studies were carried out on samples of varying moisture content (prepared by storing the materials over saturated salt solution in glass desiccators) using a Tronac calorimeter (model 458, Tronac Inc., U.S.A.). The calorimeter, which has been described elsewhere (Lindenbaum and McGraw, 1985), consisted of a reaction vessel (50 ml capacity, silvered glass, vacuum, Dewar flask) immersed in a thermostatted, insulated waterbath. The sample solid (0.2–0.6 g) was contained in a sealed, thin walled glass ampoule mounted on a rotating support (which also doubled as a stirrer for the water in the reaction vessel). After equilibration to 25°C, the ampoule was broken and the temperature rise monitored by means of a thermistor. This was compared to a similar temperature rise initiated using a heating coil in the reaction vessel and from the applied current, voltage and time the enthalpy of the reaction could be calculated. Data capture and processing were carried out using a microcomputer linked to the calorimeter via an interface. Experiments were carried out in duplicate.

Independence of the measured heat of immersion of the weight of sample used can be assessed by comparing the data generated in this study for Avicel PH101 with those from previous studies on the same material where different weights of sample were used. Fig. 1 shows that all the curves for the heat of immersion against moisture content are superimposable. The shape of the curves has been explained by both Hollenbeck et al. (1978) and Zografi et al. (1984). At low levels of moisture, water is thought to interact in a 1:1 stoichiometric ratio with the anhydroglucose units in the amorphous regions of the cellulose chain. As the moisture content rises, water interacts in a less strongly bound 2:1 stoichiometric ratio with each repeating unit followed by less well defined multilayers of water molecules. It is interesting to note that Landin et al. (1993a) have been able to relate the heat of immersion to the degree of crystallinity for a series of well defined microcrystalline celluloses.

Figs. 2 and 3 show the heat of immersion against moisture content for each of the four materials under test. While the curves are superimposable when the data were expressed on a weight basis, when corrected for surface area, the curve for Avicel PH105 is consistently lower. Similar effects have been seen with silica, alumina and titanium dioxide (Wade and Hackeman, 1961) although in these cases the data, when expressed on a weight basis, also showed the same trends. The results would thus be explained on the basis of a change in the amorphous character of the surface with decreasing particle size. No such explanation can be offered for the microcrystalline cellulose data. The reasons can only be hypothesised.

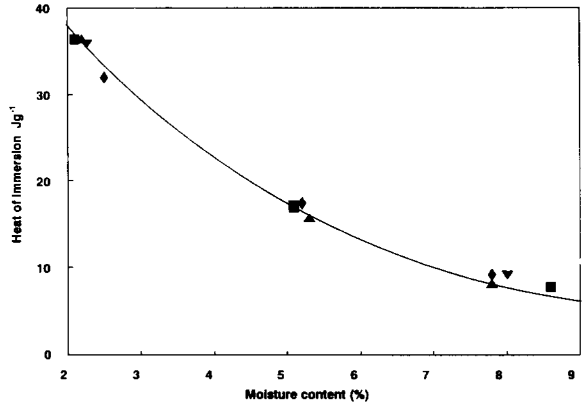

Fig. 2. Heat of immersion against moisture content for four grades of Avicel. (◆) Avicel PH105; (■) Avicel PH101; (▲) Avicel PH102; (▼) Avicel PH200. Data expressed on a weight basis.

(a) The surface area used is not indicative of the true surface area available for interaction. This may indeed be the case since recent work by Fielden et al. (1988) has concluded that microcrystalline cellulose (Avicel PH101) can be described as a molecular sponge with an effective surface area available for water absorption of 634 m^2 g^{-1}. Incidentally, Hollenbeck et al. (1978) performed a similar calculation obtaining a value of 130–270 m^2 g^{-1}. Although different, both are two orders of magnitude greater than that measured using nitrogen as the adsorbent molecule.

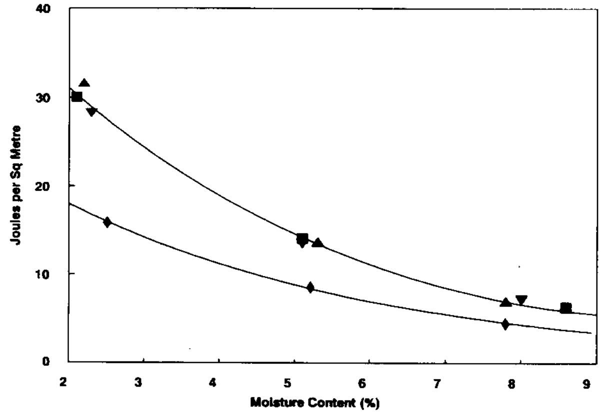

Fig. 3. As Fig. 2. Data expressed on a surface area basis.

(b) There may indeed by a difference in the interfacial energies for Avicel PH105. Evidence, albeit circumstantial, that Avicel PH105 does interact with water in a different way from the larger sizes Avicel PH101 and Avicel PH102 does exist in the literature. In rheological studies of mixtures of microcrystalline cellulose and water using mixer torque rheometry (Rowe and Sadghnejad, 1987) the maximum recorded torque (a measure of the complex viscosity of the wet mass) for Avicel PH105 was significantly lower than for Avicel PH101 and PH102 where it would be expected from simple rheological consideration to be higher (viscosity increases with increasing particle size). Hence the decrease recorded could only be due to a decrease in the interaction between the material and water. Equilibrium moisture/relative humidity curves (Handbook of Pharmaceutical Excipients, 1986) also show a decreased interaction for Avicel PH105 in that it consistently has a lower equilibrium moisture content than the larger particle size material.

In conclusion it can be seen that while there is no particle size dependence for the heat of immersion of microcrystalline cellulose when expressed on a weight basis, an anomaly does occur when the data is expressed on a surface area basis. At present the reasons for this are only a matter for conjecture although with the advent of inverse gas chromatography and an ability to probe surfaces to an even greater degree than presently available a possible definitive answer may well be found.

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