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Effect of Binders on the Formation of Pellets. I. Water, Alcohol and Alcohol–Water Mixtures

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The effect of binding liquids–water, alcohol and mixtures of the two on the pelletisation of three materials of differing solubility in water or alcohol–lactose, paracetamol and phenacetin was studied. It was found that the high solubility of lactose in water is not the only parameter affecting pellet growth and properties but it is also the greater wetting of lactose particles due to surface tension lowering by alcohol in water–alcohol mixtures. Paracetamol pellets prepared with water were small and weak but those prepared with alcohol or water–alcohol mixtures were larger and of a greater strength due to the greater solubility of paracetamol in alcohol relative to that in water. Phenacetin when pelletised with water, alcohol or water–alcohol mixtures were very soft and fragile. This suggests that for very hydrophobic material such as phenacetin, it is not sufficient to be highly soluble in alcohol but solubility in water is essential.

Keywords——pelletisation; water; alcohol; water–alcohol; lactose; paracetamol; phenacetin; binder

Pellets are spherical bodies formed from a mass of finely divided material or particles by a continuous or tumbling motion. The more important studies were directed to parameters governing the operation of the pelletiser, such as agitation speed and angle of inclination of the pelletiser as well as the amount of feed material used and the time the material is allowed to tumble in the pelletiser.[1-10] In an earlier study,[11] it was found that operating variables of the dish pelletiser had an effect on the size and properties of the pellets so formed. The first part of this current investigation deals with the influence of binding liquids such as water, alcohol and mixtures of the two liquids on pellet growth and properties. For this purpose, materials of differing solubilities were selected, lactose as representing a substance which is very soluble in water and poorly soluble in alcohol, paracetamol, which is sparingly soluble in water and very soluble in alcohol and phenacetin, which is poorly soluble in water and soluble in alcohol.

Experimental

Materials——Lactose, paracetamol and phenacetin used for pelletisation were of B. P. grade. The mean particle size and bulk densities of these materials determined are shown in Table I. The binding liquids were distilled water,

TABLE I. Particle Size, Bulk Density and Water-Solubility of Materials for Pelletisation

Material	Diameter (μm)	Bulk density (g/ml)	Water-solubility at 30 ± 0.5 °C (mg/ml)
Lactose	153.36 ± 51.73	0.7225 ± 0.003	222.22
Paracetamol	27.04 ± 16.81	0.4890 ± 0.010	0.9574—0.9614 (0.0959%)
Phenacetin	36.12 ± 22.27	0.3391 ± 0.007	13.81—14.527 (1.416%)

TABLE II. Surface Tension and Viscosity Measurements of Alcohol–Water Mixtures at 30 °C

Alcohol : water	Surface tension ($mN/m \times 10^{-3}$)	Viscosity relative to water
100 : 0	22.522±0.176	1.37
75 : 25	24.160±0.082	1.93
50 : 50	27.492±0.430	2.26
25 : 75	34.738±0.176	1.81
0 : 100	73.061±0.101	1.00

redistilled alcohol and alcohol–water mixtures.

Formation of Pellets——An inclined dish pelletiser (Erweka, Germany) as described previously[11] was employed to produce pellets. It consists essentially of a shallow cylindrical dish 40 cm in diameter, 10 cm in depth, rotating about an inclined axis. The volume ratio of feed material to the capacity of the dish is 1 : 63. The operating conditions adopted were: feed load 200 g, residence time 15 min, angle of inclination of pelletiser 45° and agitation speed 31.66 rpm. The feed material was placed in the pelletiser and allowed to rotate. The binder solution was sprayed tangentially on to the rotating material to form pellets. The pellets were dried in an oven at 60 °C for 4 h. The size analysis, bulk density, angle of repose, crushing strength and friability of pellets were determined as discussed earlier.[11]

Surface Tension Measurements——Surface tension was measured using the Rosano surface tensiometer employing the Wilhelmy plate principle. Water, absolute alcohol and mixtures of the two were equilibrated for 24 h before measurements were made at 30 °C, at 15 min inservals after the plate was immersed in the solution. Three readings were taken and averaged. The data are shown in Table II.

Viscosity Measurements——A U-tube viscometer was used. The viscosity was determined according to the method of the B. P. at 30±0.5 °C. The flow time of distilled water was 11.32±0.01 s. Five determinations were taken and averaged. The mean was expressed as viscosity relative to that of water (Table II).

Solubility Measurements——Saturated aqueous solutions of phenacetin of paracetamol at 30 °C were prepared. The amount dissolved was measured spectrophotometrically (Perkin Elmer, model 550, U.S.A.) at 245 and 244 nm for phenacetin and paracetamol respectively. The water-solubility of lactose was assessed by placing one gram of lactose accurately weighed in each of 7 beakers. Water was added to each beaker and shaken intermittently. Each beaker contained water in increments of 0.1 ml. The volume of water added just sufficient to dissolve completely all the lactose was noted.

Results and Discussion

Water

The results of the size analysis of pellets of lactose prepared with increasing amount of water, 20.0%, 22.5% and 25% (w/w) are shown in Fig. 1. With more water, the size distribution becomes broader and the mean pellet size increases. To initiate pelletisation of lactose there must be a nucleus whose moisture content is not less that 20% (w/w). When the amount of water was increased from 20.0% to 22.5%, more of the feed particles are being wetted, these then serve as nuclei and as a result of coalescence the mean pellet size increases. It was also observed that pellets formed in this way were irregular and fragmented. This is explained as being due to the very large pellets (>4 mm) produced with high water content, these then give rise to a crushing effect on the smaller pellets which lead to deformed pellets as well as fines. These fines, on subsequent tumbling, layer onto the larger pellets. Consequently, the crushing strength and bulk density generally increased with the amount of water incorporated for pellets of sieve fraction 2.0—2.8 mm and decreased for pellets of sieve fraction 1.0—1.4 mm (Table III). The reduction in bulk density is accompanied by an increase in angle of repose of the pellets, indicating that close packing of particles in the pellets is not achieved at higher water content. Crushing strength data shows that with more water the pellets of sieve fraction 2.0—2.8 mm were stronger (Table III). This is because, lactose being very soluble in water, 22.2 g/100 ml (Table I), more lactose particles will go into solution and

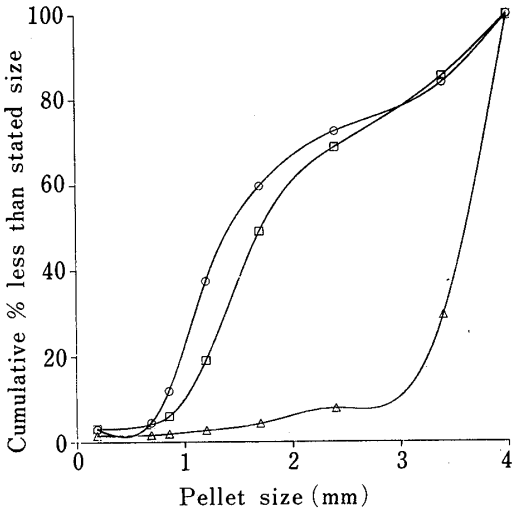

Fig. 1. Size Distribution of Lactose Pellets Formed with Different Amounts of Water as Binding Liquid

Amount of water (% (w/w)): 20 (○), 22.5 (□), 25 (△).

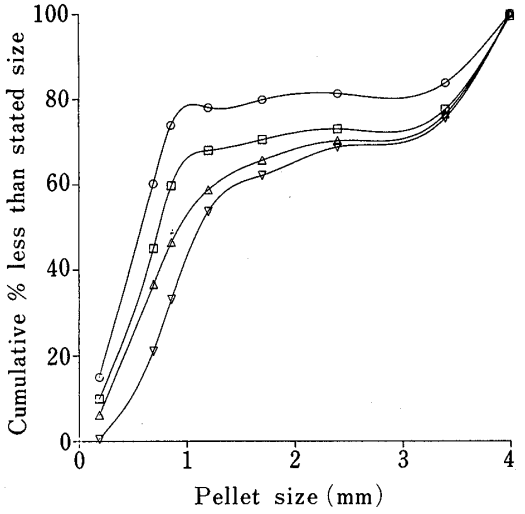

Fig. 2. Effect of Varying Amount of Water on the Size Distribution of Paracetamol Pellets

Amount of water (% (w/w)): 30 (○), 32.5 (□), 35 (△), 37.5 (▽).

TABLE III. Effect of Varying Amount of Water on Properties of Lactose Pellets of Sieve Fraction (A) 2.0—2.8 mm and (B) 1.0—1.4 mm (Confidence Interval at 95%)

	Amount of water (% (w/w))	Crushing strength (g)	Friability index	Bulk density (g/ml)	Mean angle of repose (°)
A	20.0	119.71—127.85	35.73—40.33	0.5673—0.6673	37.50
	22.5	127.54—144.17	33.40—35.78	0.5096—0.7336	38.50
	25.0	134.22—141.05	34.49—38.51	0.5372—0.5482	45.63
B	20.0	73.91—81.38	29.03—29.83	0.5997—0.6497	33.14
	22.5	67.34—72.10	27.36—30.34	0.5524—0.6264	33.83
	25.0	20.50—25.62	*a)*	0.4742—0.5982	36.53

a) Insufficient sample.

on drying more crystalline bonds are formed, giving rise to greater pellet strength. However, for pellets of sieve fraction 1.0—1.4 mm, there was a decline in pellet crushing strength (Table III). This is due to the crushing effect of the larger and heavier pellets on the smaller ones, resulting in deformed pellets and fines. The deformed pellets have weak points due to chipping and this leads to lower crushing strength values being obtained.

Various amounts of water, 30.0%, 32.5%, 35.0% and 37.5% (w/w) were used as binding liquid to produce pellets of paracetamol. The mean pellet size increased gradually for pellets with smaller quantities of water followed by a large increase for pellets with 37.5% (w/w) water (Fig. 2). Compared with the lactose–water system, the gradual increase is due to the relatively low solubility (Table I) of paracetamol in water (1.416 g/100 ml) compared with that of lactose (22.2 g/100 ml). As the water content is increased, the interstices and voids in the pellet become increasingly filled and a capillary state of wetting is achieved. Particle rearrangement occurs to give closer packing within the pellet and consequently bulk density increased (Table IV). With more water, pellets formed are increasingly cohesive, resulting in firmer pellets. In addition, some paracetamol particles go into solution and crystalline bonds

TABLE IV. Effect of Varying Amount of Water on Properties of Paracetamol Pellets of Sieve Fraction (A) 2.0—2.8 mm and (B) 1.0—1.4 mm (Confidence Interval at 95%)

	Amount of water (% (w/w))	Crushing strength (g)	Friability index	Bulk density (g/ml)	Mean angle of repose (°)
A	30.0	56.86—59.60	89.89—96.85	0.4669—0.4749	37.74
	32.5	59.92—61.24	59.62—63.22	0.4711—0.4911	36.32
	35.0	67.99—73.25	41.53—43.27	0.5005—0.5045	34.87
	37.5	122.81—124.79	26.92—27.22	0.4968—0.5148	34.20
B	30.0	9.71—12.29	59.59—64.81	0.4240—0.4320	31.61
	32.5	15.39—18.19	40.75—39.34	0.4541—0.4621	31.03
	35.0	20.62—25.02	27.86—30.10	0.4624—0.4774	30.21
	37.5	25.78—26.32	a)	0.4758—0.4938	a)

a) Insufficient sample.

are formed on drying. As a result, crushing strength values increased and friability values decreased (Table IV). With greater cohesiveness and improved packing within the pellet, stronger pellets are formed with more water, they can be kneaded into more spherical pellets as demonstrated by the reduction in the angle of repose values (Table IV).

Phenacetin pellets were formed with 30.0%, 35.0% and 37.5% (w/w) of water as binding liquid. The pellets appeared spherical and smooth, they tumbled satisfactorily in the pelletiser initially. However, with residence time of up to 15 min, these pellets become less cohesive. There is breakage of some pellets to particles. The pellets on drying are held by weak bonds and in the sieving analysis they break down further. This may be due to the hydrophobicity of phenacetin which does not promote sufficient wetting. In addition, it is much less soluble in water, 0.0959 g/100 ml (Table I) to form adequate cohesive forces to hold the pellet together.

Absolute Alcohol

The amount of absolute alcohol used to pelletise lactose was 20%, 30%, 40% and 50% (w/w). Initially, the pellets formed were soft and fragile. With further tumbling in the pelletiser, they disintegrated into smaller irregular particles. Lactose is only very slightly soluble in alcohol and thus weak cohesive forces are generated within the pellet.

In the case of paracetamol pellets, the quantity of absolute alcohol used in pelletisation was 40%, 45% and 50% (w/w). It was observed that pellets formed with 40% or 45% (w/w) absolute alcohol were weak and powdery but those with 50% (w/w) tumbled satisfactorily in the pelletiser and were sufficiently strong. Paracetamol is soluble in absolute alcohol and hence pellets can be formed which can withstand the agitation forces in the pelletiser. This will be discussed when dealing with water–alcohol mixtures as binding liquids.

As for phenacetin, the pellets produced with 40%, 45% or 50% (w/w) absolute alcohol were smooth and spherical but with more tumbling, the pellets broke down into smaller irregular pellets and finally into a powder. As in the case of lactose pelletised with absolute alcohol, the cohesive forces were too weak to resist agitation in the pelletiser. Phenacetin is very hydrophobic and although it is soluble in absolute alcohol, the pellets formed are soft and fragile, despite the lowering of surface tension by alcohol to aid wetting of the material. It has been found[12] that a surface tension below 38—40 mNm^{-1} had little effect on the adhesion tension of phenacetin and aspirin.

Water–Alcohol Mixture

From preliminary experiments it was found that for satisfactory formation of pellets, a

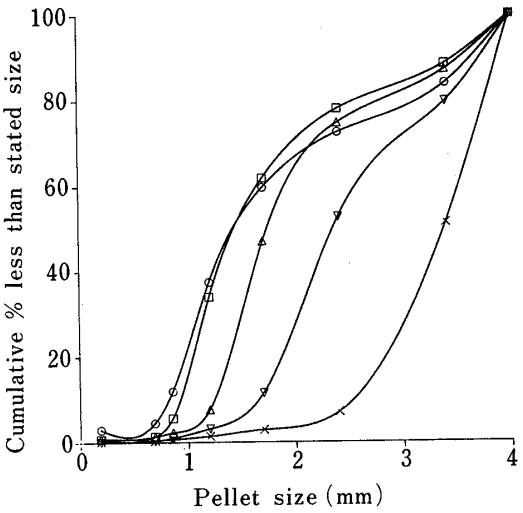

Fig. 3. Effect of Varying Amounts of Alcohol in Alcohol–Water Mixtures on the Size Distribution of Lactose Pellets

Alcohol–water; 0:10 (○), 1.11:10 (□), 4.07:10 (△), 5:10 (▽), 9.5:10 (×).

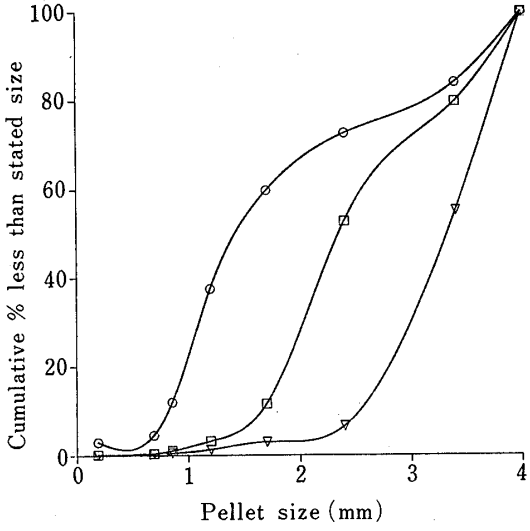

Fig. 4. Effect of Varying Amounts of Water in Alcohol–Water Mixtures on the Size Distribution of Lactose Pellets

Alcohol–water; 0:10 (○), 5:10 (□), 5:11.25 (▽).

TABLE V. Diameter of Lactose Pellets Formed with Water and Alcohol–Water Mixture in Which (A) Only the Amount of Alcohol is Varied and (B) Only the Amount of Water is Varied

	Alcohol : water		Amount of alcohol–water mixture (% (w/w))	Amount of water (% (w/w))	Average diameter (mm)
A	—	10.0	20.00		1.38
	1.11	10.0	22.22		1.40
	4.07	10.0	28.14		1.73
	5.00	10.0	30.00		2.38
	9.50	10.0	39.00		3.40
B	5.0	10.0	30.00		2.38
	5.0	11.25	32.50		3.38
				20.00	1.38
				22.50	1.70
				25.00	3.75

minimum amount of water, 20% (w/w) was required. In the following investigation, it was not practical to keep the total amount of binding liquid constant, because it can give rise to underwetting or overwetting of the feed materials, hence two sets of experiments were carried out where (i) the alcohol content was varied but the water content was kept constant and (ii) the water content was varied but the alcohol content was kept constant. Increasing the proportion of alcohol in the alcohol–water mixture, 1.11:10, 4.07:10, 5:10 and 9.5:10 respectively, it was found that the size distribution of the pellets formed tends to widen (Fig. 3). The mean pellet diameter increased gradually initially with alcohol content and then markedly when the alcohol: water was 9.5 : 10 (Table V). It was observed that with mixtures of 1.11 : 10 and 4.07 : 10 pellet growth was satisfactory. Coalescence is the predominate growth mechanism. Increasing alcohol content (with water content being maintained constant) to greater than 5 : 10 in the mixture resulted in very large pellets, > 4 mm pellets were formed which crushed the smaller pellets leading to fragmented pellets and fines, some fines subsequently layering on to the larger ones. Although the total amount of binding liquid was

not kept constant, the increase in mean pellet diameter could be due to the effect of alcohol in the mixture. Table V shows that with an increment of 2.5% of water (from 20.0—22.5%) there was an increment of mean pellet diameter from 1.38 to 1.70 mm but in the case of alcohol–water mixture for a similar increment of mean pellet dismeter the amount of mixture required for this purpose was much greater (from 20.0 to 28.14%).

Increasing the water content in the mixture, from 10:5 to 11.25:5 of water–alcohol respectively, it was found that pellet growth was very rapid as shown by the wide change in size distribution (Fig. 4). The mean pellet diameter increased sharply (Table V). Water content greater than 11.25:5 in the mixture constitute an overwetting region where large clumps or clusters of pellets were formed and ultimately paste formation occurred.

From these results, it can be deduced that small amounts/increments of water have a much greater effect than alcohol in effecting growth of pellets. In addition, the total amount of binding liquid used is also important. The greater the amount of binding liquid the more the particles can be moistened and this can soften the surfaces of particles resulting in numerous nuclei to enhance coalescence. This in turn enhances pellet growth. Table V shows that the total amount of water–alcohol mixtures had a smaller effect on pellet growth than the total amount of water when used alone.

It is seen that with increasing alcohol in the alcohol–water mixtures (Table II) the surface tension is reduced for all the mixtures. In addition, it is seen that increasing the alcohol in these alcohol–water mixtures, 0:100, 25:75 and 50:50 the viscosity is increased. The rise in viscosity increases the surface tension forces holding the particles together. This prevents the pellets from being deformed on tumbling. However, on increasing the alcohol content in the alcohol–water mixture, 1.11:10 to 9.5:10, a greater number of feed particles can be wetted due to a decrease in the surface tension of the binding liquid. As a result, very large pellets are formed which on tumbling exerts a crushing effect on the smaller pellets, bringing about fragmented pellets and fines. Crushing is also predominant when the proportion of water in the water–alcohol mixture is increased from 10:5 to 11.25:5. Thus, with a higher viscosity

TABLE VI. Properties of Lactose Pellets of Sieve Fraction (A) 2.0—2.8 mm and (B) 1.0—1.4 mm Formed with Alcohol–Water Mixtures in Which (i) Only the Amount of Alcohols is Varied and (ii) Only the Amount of Water is Varied

	Alcohol : water		Amount of binding liquid (% (w/w))	Crushing strength (g)	Friability index	Bulk density (g/ml)	Mean angle of repose (°)
A(i)	—	10.0	20.00	119.71—127.85	35.73—40.33	0.5673—0.6673	37.50
	1.11	10.0	22.22	139.52—144.46	34.18—35.06	0.5936—0.6316	37.75
	4.07	10.0	28.14	162.69—166.79	30.85—35.09	0.5633—0.6633	36.42
	5.00	10.0	30.00	178.58—184.32	30.12—34.74	0.5756—0.5956	36.90
	9.50	10.0	39.00	187.51—203.31	21.03—25.91	0.4927—0.6127	39.90
A(ii)	5.00	10.0	30.0	176.94—184.32	30.12—36.42	0.5756—0.5956	36.90
	5.00	10.0	32.5	198.15—186.81	19.00—20.66	0.5421—0.5621	39.23
B(i)	—	10.0	20.00	73.91—82.31	29.03—29.83	0.6047—0.6447	33.14
	1.11	10.0	22.22	75.70—80.56	24.93—28.51	0.5760—0.6560	33.11
	4.07	10.0	28.14	83.08—91.14	18.00—21.46	0.5902—0.6102	35.07
	5.00	10.0	30.00	55.10—63.10	17.07—22.33	0.5119—0.5319	36.28
	9.50	10.0	39.00	50.43—62.27	*a)*	0.4619—0.5819	39.80
B(ii)	5.00	10.0	30.00	55.11—63.09	14.44—22.33	0.5119—0.5319	36.28
	5.00	11.25	32.50	69.87—74.87	12.92—16.08	0.5085—0.5285	37.35

a) Insufficient sample.

and lower surface tension, there is greater cohesiveness of the particles, hence stronger pellets are produced (Table VI). Increasing the water content or increasing the alcohol content (Table VI) in the mixture produces strong pellets. The bulk density in these two cases decreased. As mentioned earlier, with more binding liquid crushing is more marked, the resultant pellets are fragmented and more fines are formed. This is responsible for the lower bulk density values obtained.

Lactose is only very slightly soluble in alcohol. The greater crushing strength is not likely to be due to increased bond formation but to increased wetting of the particle which brings about more cohesiveness of the pellets. In addition, the greater viscosity effect between particles, enhances the tensile strength of the pellets. With increased wetting, the pellets become excessively plastic, resulting in irregular and fragmented pellets which reduce the bulk density and exhibit poor flow properties as indicated by the large angle of repose measurements.

In the case of paracetamol, the water–alcohol mixtures used were 0:100, 5:95 and 15:85, whilst the amount of this mixture employed for pelletisation was 50% (w/w). Unlike previous experiments, the total amount of binding liquid could be maintained constant and 50% (w/w) was found to be optimal for this purpose. With less than this amount it was observed that the pellets produced were not strong and some portions of the feed material were not wetted uniformly. Preliminary experiments showed that when water–alcohol mixtures of 25:75, 50:50 and 75:25 were used to pelletise paracetamol, the pellets were weak and on sieving during size analysis, they disintegrate into a powder. It is seen that with increasing proportion of alcohol in water–alcohol mixture there was an increase in the mean pellet diameter (Fig. 5), pellets were larger than those formed with water only (Fig. 2). It was observed that the larger pellets had a crushing effect on the smaller pellets when the water–alcohol mixture were 5:95 and 0:100.

Paracetamol is very soluble in alcohol. The surface tension of water–alcohol mixtures have been found to decrease with increasing alcohol content (Table II). This means that more particles can become wetted and the finer material can go into solution more readily and wet the remaining solid particles. This solution fills the voids between particles and thereby achieve a closer packing as shown by the greater bulk density for pellets of sieve fraction 2.0—2.8 mm (Table VII).

The crushing strength of paracetamol pellets increased and the friability decreased with a higher alcohol content in the binding liquid (Table VII). As more paracetamol particles are dissolved in alcohol, a greater number of bonds are formed. The slight reduction in crushing

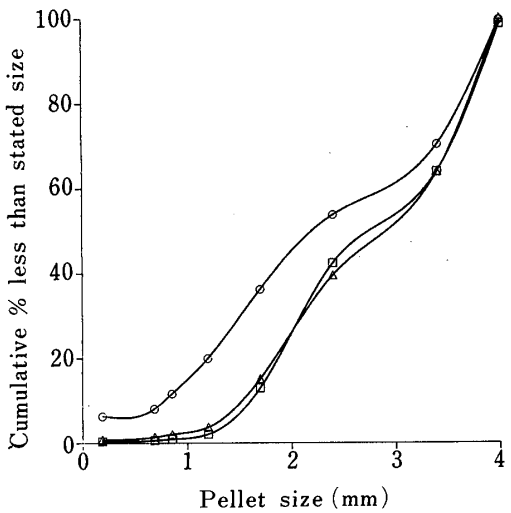

Fig. 5. Effect of Water–Alcohol Mixtures on the Size Distribution of Paracetamol Pellets

Alcohol–water; 85:15 (○), 95:5 (□), 100:0 (△).

TABLE VII. Effect of Water–Alcohol Mixtures on Properties of Paracetamol Pellets of Sieve Fraction (A) 2.0—2.8 mm and (B) 1.0—1.4 mm

	Alcohol : water	Crushing strength	Friability index	Bulk density (g/ml)	Mean angle of repose (°)
A	85 : 15	177.38—187.26	13.92—19.04	0.5395—0.6395	34.87
	95 : 5	252.24—270.58	6.48— 8.24	0.5507—0.5587	32.17
	100 : 0	340.84—390.94	11.11—13.54	0.5571—0.5691	35.07
B	85 : 15	47.11— 55.13	20.89—27.05	0.4813—0.5053	32.31
	95 : 5	124.75—131.91	10.60—15.20	0.4979—0.5119	34.17
	100 : 0	100.63—118.31	a)	0.4659—0.4859	35.12

a) Insufficient sample.

TABLE VIII. Influence of Polysorbate 80 Solution as a Binding Liquid on the Properties of Pellets of Phenacetin of Sieve Fraction 2.0—2.8 mm

Polysorbate 80 concentration[a] (% (w/w))	Bulk density (g/ml)	Mean angle repose (°)	Friability index
0.33	0.4806—0.4906	36.82	46.43
0.67	0.4855—0.5035	35.90	33.20
1.00	0.4953—0.4993	33.56	25.83

a) Amount of polysorbate 80 solution used in 32.55% (w/w).

strength of pellets of sieve fraction 1.0—1.4 mm prepared with water–alcohol mixture of 0 : 100 is due to fragmented pellets obtained in this size range. Compared with paracetamol pellets prepared with water alone as the binding liquid, these paracetamol pellets formed with water–alcohol mixtures and alcohol alone are larger, compact, dense and of greater mechanical strength. This is because paracetamol is soluble in alcohol and only slightly soluble in water. Besides, surface tension lowering provides greater wetting of the feed material and hence enhances rate of growth of pellets.

In the case of phenacetin, the water–alcohol mixtures used as binding liquids were of these proportions 0 : 100, 5 : 95, 10 : 90, 15 : 85 and the amount of mixture employed was 45% (w/w). Pellet formation was satisfactory with water–alcohol mixture of 5 : 95 but on further tumbling in the pelletiser the cohesive forces were not adequate to hold the pellet together. With water–alcohol mixtures of 15 : 85 and 10 : 90 very few pellets could be formed. Inspite of the reduction in surface tension brought about by using alcohol and water–alcohol mixtures to aid wetting, cohesive forces of sufficient strength were not generated by these liquids. When polysorbate 80 solutions of concentrations 0.33, 0.67 and 1.0% (w/w) were used to pelletise phenacetin, the resultant pellets (*cf.* water and alcohol) were strong and able to withstand tumbling in the pelletiser. As shown in table VIII increasing the concentration of polysorbate 80 produces stronger pellets as shown by the decrease in friability. In addition, due to the cohesive forces of the pellets, the pellets can be kneaded into more spherical pellets, as is evident in the lower values of mean angle of repose and they are capable of greater packing capacity as seen in the bulk density values obtained. This increase in cohesive forces within the pellet could be due to the lowering of the contact angle of the feed material by polysorbate 80, which is surface active. It was observed that the surfactant renders the phenacetin particles adhesive.

Conclusions

From the findings of this investigation, it is shown that solubility of the feed material in the binding liquid is not the only factor affecting both pellet growth and properties. Though lactose (very soluble in water) is only slightly soluble in alcohol, the increase in pellet growth and pellet strength is due to a greater wetting of lactose particles as a result of surface tension lowering and thereby increasing the number of nuclei for coalescence to occur. This wetting effect can result in greater cohesiveness between particles. Alcohol, when used alone has no binding capacity though the surface tension reduction was very marked. Thus, it is shown that though alcohol enhances wetting of feed material, it is required in minimum amounts to act as a binder.

Paracetamol is only slightly soluble in water and pellets formed with water were small and weak. Alcohol as a binding liquid effected a large increase in pellet size and strength when compared with those pelletised with water only. This is because paracetamol has a greater solubility in alcohol than in water. When the alcohol content of water–alcohol mixtures used to pelletise paracetamol was increased there was also an increase in pellet size and strength.

Pellets of phenacetin prepared with alcohol, water or water–alcohol mixtures were soft and friable but those prepared with polysorbate 80 solutions were more firm and less friable. For hydrophobic materials, a binding liquid with low surface tension and in which the feed material is highly soluble is not necessarily appropriate for pelletisation, the binding liquid should also impart adhesiveness to the material.

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