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FOAM SPRAY DRYING METHODS OF MAKING READILY DISPERSIBLE NONFAT DRY MILK

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SUMMARY

A method of making a readily dispersible nonfat dry milk by injection of gas into the high-pressure feed line is described and compared with the conventional process for making an instantized powder. The foam spray drying method produces a quickly dispersible product during drying without a subsequent agglomerating step; it permits a greatly increased dryer output, since gas injection improves the efficiency of water removal and makes possible the drying of skimmilk concentrates up to 60% solids; it reduces costs of instant powder manufacture by requiring only minor equipment changes which do not affect the efficiency of the dryer to produce standard type powder. The one-step foam spray dried particle differs from the two-step agglomerated particle, in that it contains gas vacuoles in its structure which, on reliquefying, cause the particle to float before it rapidly dissolves, and more foam to form on the milk surface.

One of the outstanding developments in the dairy industry in recent years has been the production of instant nonfat dry milk (NDM). In 1961, production amounted to more than 200 million pounds, or 10% of the total NDM made in the United States. It is chiefly a retail item that is bought by the housewife and consumed in the home.

Conventionally, skimmilk is forewarmed to at least pasteurize it, condensed in a suitable evaporator to 40 to 45% solids, and the concentrate dried by the spray method. In a second and independent operation, the spray-dried powder is exposed to a warm and humid atmosphere to cause the particles to agglomerate and the excess moisture, amounting to about 6 to 12%, is removed with hot air. In the course of this operation part of the lactose crystallizes as the alpha hydrate isomer. Large and expensive equipment is required. The cost of instantizing is variously estimated at about 1 to about 2 cents per pound of final product.

With this method of instantizing, care must be taken to prevent protein denaturation, the formation of burned particles, and the loss of solids. However, recent improvements tend to minimize or avoid these undesirable side effects.

A product so instantized has a bulk density in the .30 to .40 range. On being added to water, it sinks and has a dispersibility of about 90 to 100% as determined by the method that will be described later.

A skimmilk concentrate that contains 40 to 45% solids is free-flowing, can be cooled and stored overnight, and is easy to dry. Commercial double- and triple-effect vacuum-evaporators are designed to reach this concentration and to do it economically. In fact, in comparison with the evaporation of water in a dryer at atmospheric pressure, the cost of steam is only 10% as much, or even less, per pound of water removed. It would, therefore, be economically advantageous to make a skimmilk concentrate containing 55 to 60% solids for drying rather than one containing 40 to 45%. Not only would there be a saving in steam but the output of a dryer could be greatly increased.

No difficulty is experienced in drying a 45% skimmilk concentrate in commercial spray-drying equipment. But, when the solids content is increased to about 49%, the moisture in the powder is usually too high. By suitably modifying methods developed in these laboratories (1, 2) high-solids concentrates (49 to 60%) have been satisfactorily dried by injecting compressed air or nitrogen into the product line between the high-pressure pump and the atomizer of the dryer. The method has been designated foam spray drying because the gas forced into the feed line at high pressure creates a skimmilk foam which is released at the nozzle. A description of the new process, together with analytical methods and experimental results, is the subject of this paper.

EXPERIMENTAL PROCEDURE

Nonfat dried milk was manufactured in the dairy products pilot plant according to the flow diagram shown in Figure 1, except that a single-effect falling-film evaporator was used to concentrate the milk. In the first pass through the evaporator the skimmilk was condensed to 27-

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TABLE 1

Effect of seeding skimmilk concentrates with alpha lactose hydrate and crystallizing on the amount of crystalline alpha lactose hydrate in foam spray dried powder

Solids in concentrate	Seeded	Crystallizing period after seeding	Temperature of concentrate	Moisture in powder	Bulk density Water = 1	Dispersibility	Crystalline alpha lactose hydrate in NDM
(%)		(min)	(F)	(%)		(%)	(% of total lactose)
52.8	No	....	100-95	3.6	.37	94.8	4.3
51.8	Yes	15	95-90	2.8	.34	94.4	7.7
51.8	Yes	35	95-90	2.8	.34	91.0	17.1

Skimmilks forewarmed at 165 F for 20 sec.

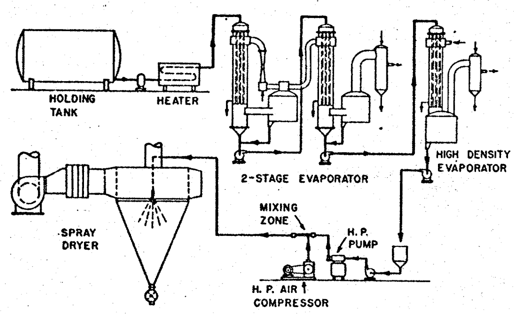

FIG. 1. Flow diagram of foam spray drying process.

30% solids. In the second pass the solids were raised to 45%, whereas in the final pass the concentration attained was 50 to 60% solids. After each pass the milk was collected in a vat and held until the evaporator was free to act as the next effect. Recirculation was necessary in the second and third passes, to reach the required solids content. It is expected that commercial evaporating equipment would be arranged as portrayed in Figure 1, so that the evaporators would continuously furnish concentrate of the desired solids to the dryer without recirculation.

A Brookfield viscometer model LVF was used to determine the viscosity of the skimmilk concentrates. Viscosity values are expressed in centipoises (CP). The amount of crystalline alpha lactose hydrate in the NDM was measured by the method of Sharp and Doob (5). It is expressed as the percentage of total lactose present.

Lactose was crystallized in some concentrates because of the belief that this lessens the tendency to absorb water. After crystallization, the concentrate was dried without preheating. Lactose crystallization in the concentrates was carried out in a jacketed kettle equipped with scrapers and double-acting stirring blades that rotated at about 10 rev/min. By this means crystallization of lactose was encouraged, a more uniform temperature was maintained and viscosity increase in the skimmilk concentrate was retarded. After drying, the amount of crystalline alpha lactose hydrate in the powders was determined. For seeding, 325-mesh alpha lactose hydrate was dispersed in an equal weight of cold water and added to the concentrate at the rate of 100 g of lactose per 100 lb of concentrate.

Drying was done in a 9-ft Gray-Jensen[2] type cyclone dryer equipped with a pressure nozzle. In this work, the dryer usually was operated at an incoming air temperature of 280 F and an outgoing air temperature of 155 F. Original rated capacity is 200 lb of powder per hour. Foam spray drying was accomplished as previously described (1, 2), by injection of compressed air into the product line just upstream from the atomizer. The quantity of gas used in each experiment is shown in the data of Table 2.

All powders were sifted through a 10-mesh sieve. Moisture determinations were made by the Bidwell and Sterling (4) toluene distillation method; bulk density by determining the weight per milliliter of a lightly tapped 10-g sample; and dispersibility by adding 10 g of powder at room temperature to 100 ml of 37 F water, stirring manually for 1 min, and filtering quickly, first through a 100-mesh stainless-steel funnel, then through a 150-mesh stainless-steel funnel placed beneath the first, and finally through a sintered glass filter with suction. Dispersibility is expressed in terms of percentage by relating the per cent of solids in the filtrate to the per cent of solids in the reconstituted skimmilk. A dispersibility of 90% is considered fairly satisfactory.

RESULTS

In a representative experiment skimmilk was heated in a suitable heat exchanger to 165 F

[2] Reference to certain products or companies does not imply an endorsement by the Department over others not mentioned.

TABLE 2

Effect of various drying conditions on the properties of foam spray dried nonfat milk

Experiment	Nozzle orifice	Solids in concentrate	Temperature and viscosity of concentrate		Gas/gal of concentrate	Moisture in powder	Dispersibility	Bulk density Water = 1
(no.)	*(in.)*	*(%)*	*(F)*	*(CP)*	*(SCF)*	*(%)*	*(%)*	
1	.040	54.0[a]	115	1,300–10,000	2.0	1.8	91.8	.33
	.040	55.1	95	2,200–19,000	2.0	2.8	85.0	.42
2	.040	56.3	90	2,300– 5,000	2.5	2.0	93.0	.28
	.040	57.3	90	2,500–13,400	1.5	2.4	86.4	.32
	.040	58.1	90	3,400–22,000	1.0	3.6	81.2	.39
3	.040	54.0	91	800	1.8	4.2	96.8	.36
	.040	54.0	91	1,100	1.4	4.4	95.0	.37
	.040	54.0	91	1,600	.9	5.0	94.6	.39
4	.046	50.0	90	300	1.5	4.6	97.0	.29
	.046	50.0	90	300	1.0	4.6	100.0	.31
	.046	50.0	90	300	0.5	4.8	97.8	.33
	.046	50.0	90	300	0.25	5.2	99.9	.35
5	.050	60.6[b]	87	1,300	2.3	4.4	100.0	.31
	.050	60.6	87	1,200	1.9	5.2	100.0	.32
	.050	60.6	87	1,000	1.5	5.6	99.5	.33

[a] All skimmilks forewarmed 165 F—15 to 20 sec.

[b] Note the large nozzle orifice and high solids in the concentrate. Rate of flow of the concentrate was 1.3 gal/min, instead of the usual rate of 1.0 gal/min. Estimated output was more than double the rated capacity of the dryer.

and concentrated in the falling-film evaporator to 52.8% solids content, the time in transit to the evaporator being 20 sec. The concentrate was divided into three parts. The first portion was foam spray dried without delay and without seeding, using an .047 nozzle and 270 F drying air. The hydraulic pressure was 1,800 psig and the pressure of the gas as it entered the product line was 2,000 psig. The rate of flow of the gas into the product line between the pump and the atomizer was one standard cubic foot (SCF) per gallon of concentrate being pumped. The second portion of the concentrate was seeded, stirred slowly for 15 min, and dried without warming, as in Part One. A third portion of the concentrate was seeded, stirred for 35 min, and dried under the same conditions as the two other portions. Further details and results are given in Table 1.

In other similar experiments in which forced crystallization was continued about an hour instead of 35 min and the 50 to 55% solids condensed skimmilk then foam spray dried without heating, it was found that the resulting powder contained as much as 35% of its lactose in the crystalline alpha hydrate form. Commercial brands of instant NDM contained from less than 5 to 25-30%.

Since the viscosity of a 51.8% concentrate ranged from 240 to only 1,240 CP, it was decided to increase the solids content of condensed skimmilk and study the effect on viscosity and other pertinent factors. Figure 2 shows the effects of the solids content and the lactose crystallizing temperature on the increase in viscosity of the concentrate with time. Since the first viscosity measurement was not made until 5 to 10 gal of concentrate had been collected and the material seeded, most of each concentrate was 10 to 20 min older than the curves indicate.

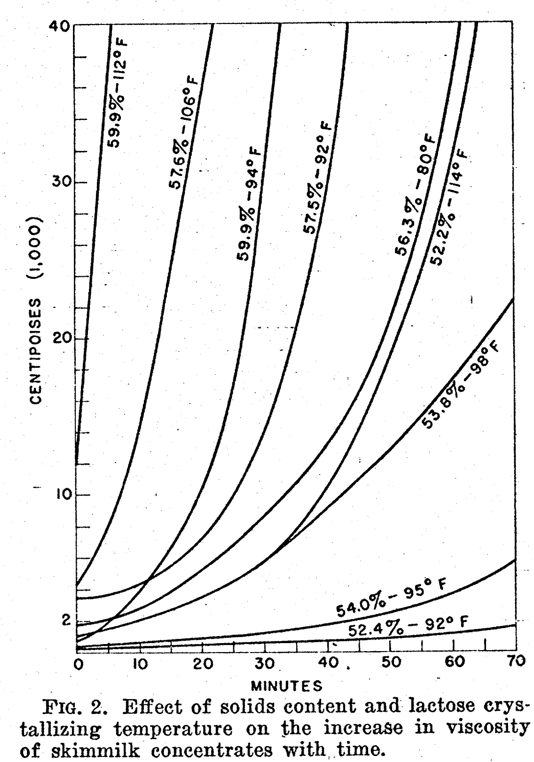

FIG. 2. Effect of solids content and lactose crystallizing temperature on the increase in viscosity of skimmilk concentrates with time.

The results of a study of various drying conditions on the moisture content, dispersibility, and bulk density of some foam spray dried nonfat powders are shown in Table 2.

It was observed in pilot plant operations that it was easier to clean the dryer and there were fewer fines because the powder particles were larger and more uniform in size than in conventional drying.

DISCUSSION

The results suggest that problems in foam drying, aside from the engineering aspects, are concerned with the degree of concentration that can be attained for the dryer feed and the handling of the concentrate to obtain the best possible product.

An important advantage of foam spray drying is that gas injection makes it possible to dry milks of much higher than the usual concentration. This permits a saving in the cost of water removal, since more water can be removed in the vacuum evaporators where costs are less than in a dryer at atmospheric pressure.

This can be further illustrated as follows: Each 100 lb of skimmilk is first reduced by vacuum evaporation to approximately 20 lb of 45% concentrate, of which 11 lb is water. If 5.5 lb, or approximately half of the remaining water is removed in a high-density evaporator to give a 60% concentrate for drying, this will reduce the amount of water that must be removed in the dryer to half of what it would have been if the 45% concentrate were dried. If water could be evaporated as readily from a high-solids as from a low-solids concentrate, the output of a dryer could be doubled. Actually, this may not be attainable in most cases, but the increased dryer capacity will be closely related to the increased solids content of the milk that is dried.

It follows that a manufacturer of NDM who is faced with the problem of providing increased capacity could, by increasing the solids content of his skimmilk concentrate, as indicated in Figure 3, increase the output of his dryer. Instead of having to purchase additional vacuum-evaporating and drying facilities, only the former might suffice. He could use existing equipment to make a 35% concentrate, thus increasing the volume of skimmilk passed through the evaporator, and add a concentrator to further condense to 55 to 60% solids, and install a relatively inexpensive gas injection unit on his existing dryer. Figure 3 shows that if 70 lb of powder is made from 40% solids milk, 160 lb can be made from 60% milk with the evaporation of the same amount of water in the dryer.

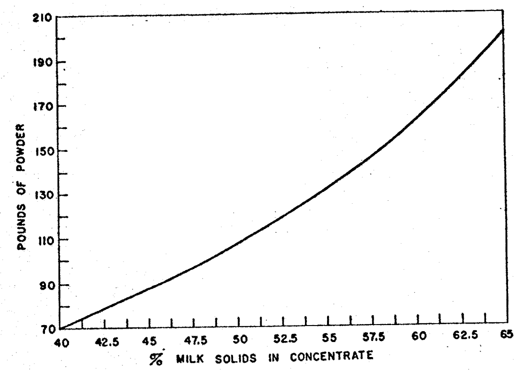

FIG. 3. Relationship between solids content of milk concentrate and output of powder per 100 lb of evaporated water.

It will be seen that concentrates in the 50 to 55% solids range increased in viscosity at a relatively slow rate over a period of an hour or more when maintained at 95 F or below. Consequently, lactose present in excess of saturation in such concentrates can be crystallized prior to drying with relatively little concern for the development of too high viscosity. However, skimmilk concentrates that contained more than about 55% solids increased in viscosity at a much faster rate, and especially so when they were removed from the evaporator at 105 F and were held at this or a somewhat higher temperature. If such concentrates are removed from the evaporator at or near 105 F, they should be cooled quickly to a temperature of about 90 F that will retard the viscosity increase during a crystallizing period. Concentrates should not be heated at any time between the evaporator and the dryer. If a skimmilk concentrate of unusually high solids content, such as 60%, is removed from an evaporator at or near 100 F, it should either be dried without delay in a continuous operation or be cooled immediately to help retain its fluidity.

The rate of lactose crystallization in sweetened condensed milk is known to be greater at 86 F than at any lower temperature where lactose is, of course, less soluble (3). Also, as the concentration of lactose in the water phase of condensed milk is increased, there is an increase in the temperature at which the maximum rate of crystallization takes place. In a solution in which the lactose-in-water percentage is 43, as it is in condensed skimmilk of approximately 60% solids content, the optimum temperature for forced crystallization, on the basis of per cent lactose in water, is in the neighborhood of 120 F. But, in order to retard the rate of viscosity increase, the crystallizing temperature should be lower. In general, the temperature of the 50 to

60% solids skimmilk concentrate should be 90 F or lower during a holding period, whether or not an attempt is made to force crystallization.

A further reason for handling the concentrate at 90 F or lower is shown by the data in Table 2, Experiments 1 and 2. In Experiment 1, the viscosity of one of the concentrates increased to 19,000 CP before drying had been completed. Bulk density of the NDM was high, but the dispersibility of 85% was low. On the other hand, in Experiment 5, where the solids content of the concentrate was 60.6% and the viscosity not more than 1,300 CP, bulk density was not high and dispersibility was 100%.

Foam spray dried NDM of high dispersibility can be made from high solids (55 to 60%) as well as from lower solids concentrates, provided the viscosity of the concentrate is low before drying. On the other hand, a concentrate of high viscosity (over 5,000–10,000 CP), regardless of solids content, yields a powder of relatively low dispersibility.

While it can be demonstrated that foam spray dried NDM containing 20% or more of its lactose in the crystalline alpha hydrate form is not as hygroscopic as that containing less than 5%, the difference is small. What is of paramount importance is the physical characteristics of the powder particles. In general, the larger they are the lower the bulk density of the powder, the better the dispersibility of the powder and the less is its tendency to absorb water and to cake. At the same time the powder must have been made in such a way as to avoid incipient denaturation of the protein resulting from agglomeration of the casein micelles, as reflected in a too great increase in the viscosity of the concentrate.

The bulk density of foam spray dried NDM is influenced by several factors, as indicated in Table 2. Among these factors is the rate at which the compressed gas is injected into the product line (Experiments 3 and 4). Other factors being equal, the lower the solids content of the material being dried, the less gas is needed to effectuate drying. The use of more gas than is needed to dry effectively results in an unnecessary lowering of bulk density. As a guide, based on our pilot plant results, no gas is needed to satisfactorily dry a 45% solids skimmilk concentrate; 0.5 SCF per gal of a 50% concentrate; 1.0 SCF per gal of a 55% concentrate; and 1.5 SCF is needed to successfully dry concentrated skimmilk containing 60% solids. These are minimum amounts.

When foam spray dried NDM is added to water it does not sink. On being stirred or shaken in cold water it disperses and an unstable foam forms on the surface of the reconstituted skimmilk. Conventionally instantized NDM sinks on being added to water and less foam appears on the surface of the reconstituted skimmilk.

What has been said about foam spray drying skimmilk concentrates applies in a general way to other lacteal concentrates such as milk, ice cream mixes, and modifications thereof, buttermilk, whey, and malted milk concentrates, all of which have been dried successfully by this method to yield instantized, free-flowing products.

CONCLUSIONS

Advantages of the foam spray drying method over the conventional method of making instantized NDM are as follows:

1. The ability to produce an instantized product in the spray dryer. No further processing is necessary.
2. Economy is realized by removing more water in the evaporator at approximately one-tenth the cost of removing the same amount of water in the dryer.
3. Increased capacity of the dryer by the removal of extra water in a concentrator.
4. A plant operator can produce either a standard type powder or an instantized powder and thus tailor his production to his sales requirements.
5. The cost of the additional equipment is relatively small compared to the total cost of the original equipment.

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