

Superior Characteristics of Flake Salt from a Multi-plate Crystallizer

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Flake salt comprised of mostly fragmented tremie and cubic crystals, produced from saturated brine in a multiplate evaporation crystallizer, exhibits better dissolution, adhesion, and mixing characteristics than conventional cubic salt, and superior performance in food product applications.

1. INTRODUCTION

Salt was traditionally produced in Japan by simmering concentrated brine in open pans, resulting in a product, which included flake-form salt and is therefore commonly referred to as fake salt. For higher energy efficiency and productivity, however, salt makers gradually developed and now widely employ closed-vessel systems incorporating evaporation steam re-use. In such systems, the evaporation occurs largely in the regions of churning within the boiling brine, resulting in a product salt which is composed almost entirely of cubic-form crystals and is commonly referred to as cubic salt.

It has long been recognized that flake salt may offer better loft, dissolution, and water retention

properties than cubic salt, and with the recent growth in the range of food choices and dietary preferences, a demand has rapidly developed for a salt that would provide the unique properties of the traditional flake salt.

To meet this demand we have developed a new flake salt (FS) and the process for its production, in which the flake form crystals are made as thin as practicable without a significant loss in their physical strength, to maximize the inherent flake salt characteristics. FS is now produced and marketed under the brand name KSLTM. Here, we describe our investigation of its characteristics, and its performance in several food product applications.

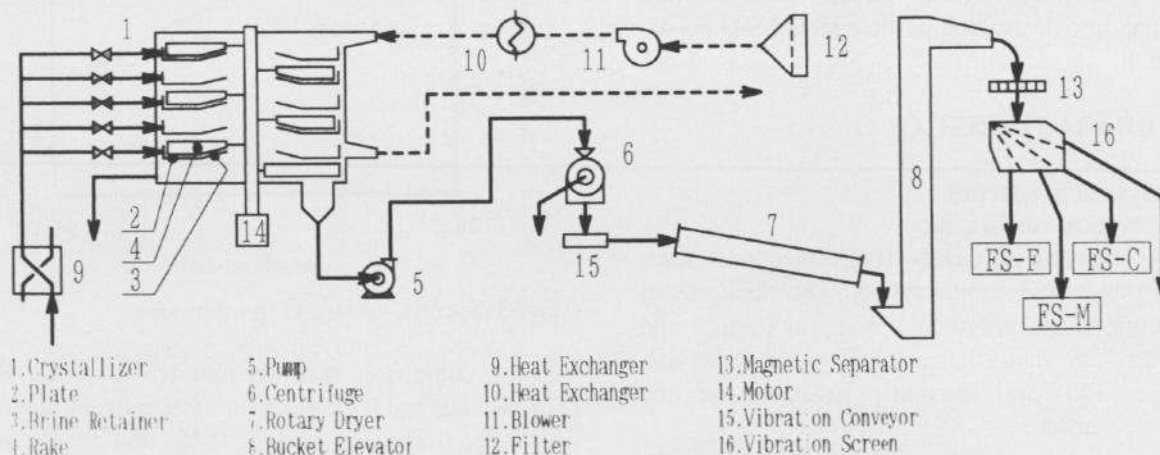


Fig. 1 FS production process

2. PRODUCTION PROCESS

As shown in Fig. 1, the crystallizer contains five disk-shaped pans, with openings in their centres. Saturated brine is fed to each pan through two nozzles at opposite points on its circumference. Evaporation occurs at the surface of the hot brine, accelerated by circulating hot air across the plate surface to obtain a FS production rate of approximately $14 \text{ kg/m}^2/\text{hr}$.

The crystals are harvested by a rake revolving around the plate axis, as shown in Fig. 2, which moves them through the brine toward the center and up the brine retainer incline, and they leave the pan through the center opening.

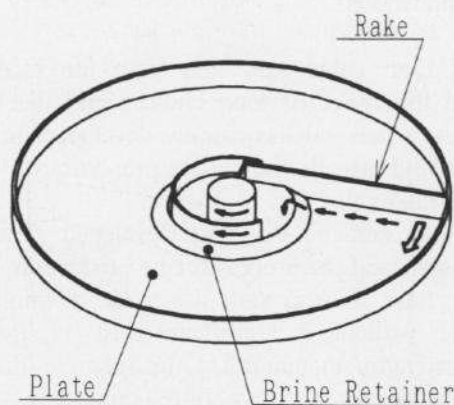


Fig. 2 Crystal harvesting process

The crystals are then fed in turn to pusher centrifuge to remove excess water, to a rotary dryer, and to an inclined vibrating screen, where they are separated into decreasing particle sizes FS-Q FS-M, and FS-F.

3. FS CHARACTERISTICS

3.1. Physical properties

3.1.1. Physical conformation

FS is composed of mostly fragmented and some whole tremie and cubic crystals. The thickness of the tremie crystal fragments is approx. $60 \mu\text{m}$, and thus far less than that in any other flake salt (approx. $140 \mu\text{m}$) currently available on the Japanese market.

3.1.2. Particle size

Average particle sizes of FS-C, FS-M, and FS-F are 0.47, 0.17, and 0.14 mm, respectively.

3.1.3. Bulk density

The bulk densities of FS-C, FS-M, and FS-F are 690, 740, and 820 kg/m^3 , indicating a greater loft in these salts than in cubic salts, which show bulk densities above $1,000 \text{ kg/m}^3$ at comparable particle sizes.

Tremie crystals generally form at the surface of undisturbed brine, in cases where the crystal nucleus is prevented from sinking by the surface tension and crystal growth proceeds only at the brine surface, resulting in a crystal having a hollow inverted pyramid configuration, with the quadrilateral base at the brine surface and the apex gradually submerging farther into the brine under the weight of the growing crystal. The term "tremie", or alternatively "hopper", refers to the inverted-pyramid configuration of the crystal.

3.1.4. Specific surface

Specific surface area, which is a fundamental parameter for elucidation of dissolution rate and other characteristics, was measured by BET multipoint analysis using krypton as the adsorption gas, in the following determinations for FS and cubic salt.

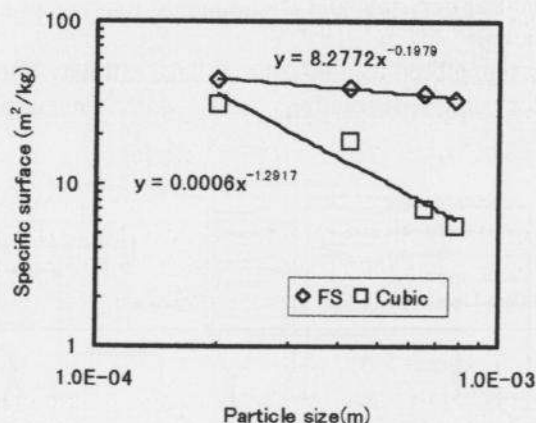


Fig. 3 Specific surface vs. particle size

FS or cubic salt was separated into 0.71-0.85, 0.355-0.50, and 0.15-0.25 mm fractions, by sieving on 0.85, 0.71, 0.50, 0.355, 0.25, and 0.15 mm mesh screens, and the specific surface was

determined for each fraction, using the mid-point of each particle size fraction (thus 0.78, 0.43, and 0.20 mm, respectively) for the calculation.

As shown in Fig. 3, the FS showed a larger specific surface than the cubic salt at all particle sizes, but the difference diminished with decreasing particle size and by extrapolation from the curves would apparently disappear at a particle size of approx. 0.16 mm.

This is in accord with the micrographs of Fig. 4, which show that the proportion of cubic crystals in FS increases with decreasing particle size.

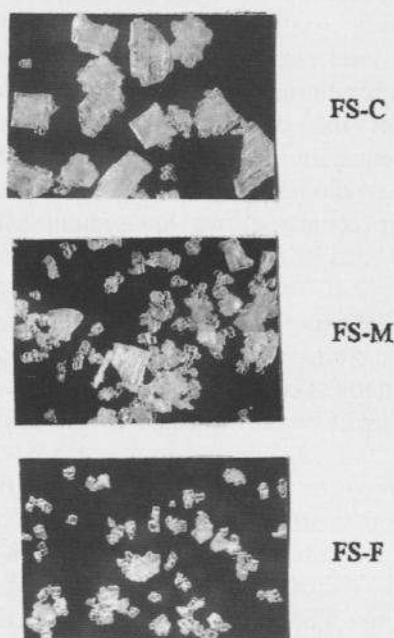


Fig. 4 Optical micrographs of FS-C,-M,-F magnification $8.8\times$, $1\text{cm}=1136\text{microns}$

3.2. Dissolution rate

In applications where the salt will be used in solution, rapid formation of a high concentration aqueous salt solution is generally advantageous.

3.2.1. Test method

The procedure was the same as that commonly employed in industry. A beaker was filled with salt solution, the salt sample was added all at once, and the rise in concentration under mixing by an impeller was measured at given intervals.

The equipment and materials were: a 100 mL beaker 50 mm in diameter; 100 mL aqueous solution containing 28 g NaCl; samples of the same

salts as those used in the specific surface determination; a vertical concentric impeller driven at 200 rpm having three paddles of 36 mm length and 9 mm width attached at 33° from horizontal with the lower edge 5 mm from the bottom of the flask; and a 25°C water bath.

Periodically, 0.2 mL of the solution at a depth of 10 mm was obtained in a pipette with its tip covered by gauze to prevent entry of the crystals, and its concentration was measured on a light refraction analyzer [1].

3.2.2. Results

In all cases, the speed of the rise in concentration was higher with FS than with the cubic salt, and increased with decreasing particle size, as shown in Fig. 5-7. The rise during the first minute was used to calculate the dissolution rate for each sample because of the relatively high accuracy of that value

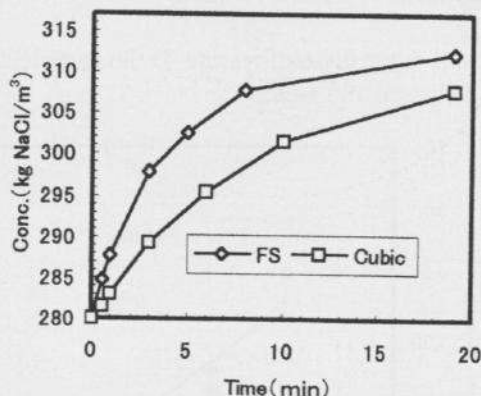


Fig. 5 Dissolution of 0.78mm (midpoint) fraction

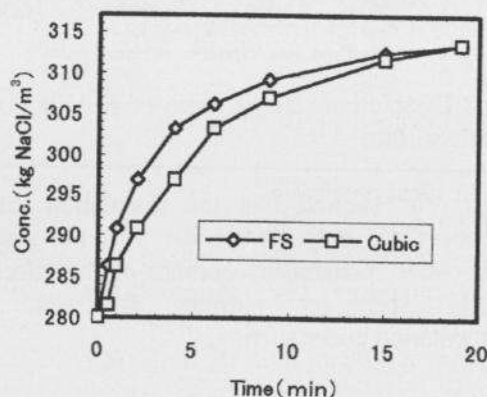


Fig. 6 Dissolution of 0.43mm (midpoint) fraction

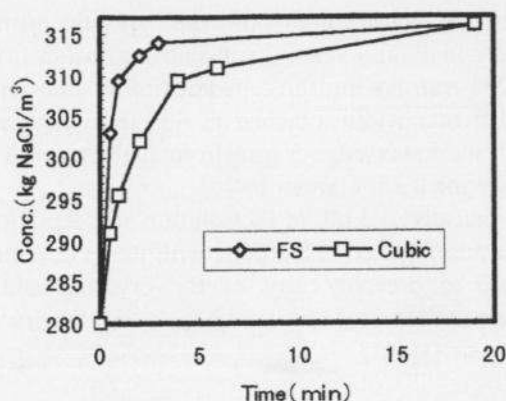


Fig. 7 Dissolution of 0.20mm (midpoint) fraction

As shown in Fig. 8, the relation between the specific area and the dissolution rate for FS and cubic salt as derived from these results was

$$R \text{ (kg/m}^3\text{/min)} = 253.64 \times (D/S)^{-0.012} \quad (1)$$

where R is the dissolution rate, D the particle size, and S the specific area.

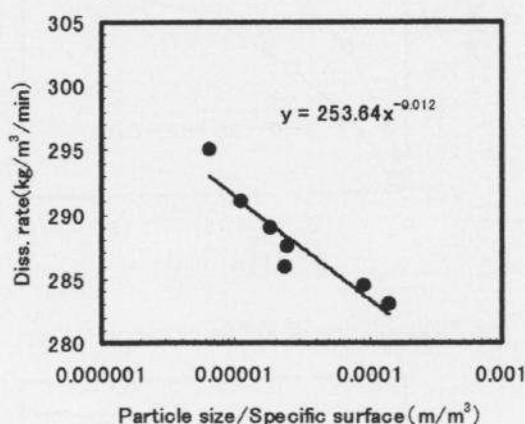


Fig. 8 Dissolution rate vs. ratio of particle size to specific surface

The results showed that the dissolution rate is dependent not only on specific area but also on particle size, presumably because of the effects of particle size on particle dispersion and sedimentation under stirring.

3.2.3. Application trial

An organoleptic trial was performed to investigate the effect of the faster FS dissolution in low-sodium seasonings, which are commonly used in cases of hypertension and other problems requiring reduced sodium intake and in which KCl is substituted for 50 wt% or more of the NaCl, usually resulting in a weakened salt flavor and a bitter taste associated with the KCl.

In general, the strength of a given flavor may be expressed as follows [2].

$$R = (R_s \times K \times C) / (1 + K \times C) \quad (2)$$

where R is the taste response, R_s is its maximum value, K is the equilibrium constant, and C is the concentration of the substance stimulating the response. This equation implies that increasing the dissolution rate should result in a stronger salt taste. In the trial, we compared two low-sodium salts composed of 50 wt% KCl and 50 wt% NaCl (mean particle sizes 0.46 and 0.43, respectively). Evaluation was by two-point comparison, in which a panel of nine subjects rated the strength of the salt taste and the bitterness of the two salts on a scale of 0-3, with the significance evaluated by Student's t -test.

The results showed the composition containing the FS to impart both a stronger salt flavour and less bitterness than the cubic salt composition, with a P value of 0.05, indicating that the more rapid dissolution of the FS can effectively mask the bitterness of the KG component.

3.3. Mixability

Mixability, defined broadly as both ease of mixing and resistance to stratification or other physical separation, is a key characteristic of the salt as an ingredient for seasonings and other formulations comprised of mixed solids.

3.3.1. Test method

Each of the following determinations of mixed formulation composition was made from five of ten test samples, with the quantity of each sample sufficient for the determination but equalling no more than one-fiftieth of the total quantity of the formulation by weight.

The degree of mixture was determined in terms of mean deviation from the average, calculated as

$$M = (100/N) - \Sigma|(X_i - X_0)/X_0| \quad (3)$$

where N is the number of samples measured, X_i the measured salt content of each sample, and X_0 the average of the measured values (and thus the overall salt content).

The percentage M thus decreases with increasing degree of mixture, and is zero for a completely uniform mixture.

The ingredients were 245 g of FS-C or cubic salt (both with mean particle sizes of 0.47 mm as determined by 50% sieve passage) placed in a 450 mL glass bottle, to which 2 wt% of tri-calcium phosphate was added and then mixed as follows.

Ease of mixing was evaluated by rotating the stoppered bottle about its horizontal centre axis once every two seconds a total of twenty times, then removing the stopper and taking samples in turn as the contents were poured from the bottle, and measuring the salt content of each sample.

Separation resistance was next determined by turning the stoppered bottle upside down, tapping it once every second a total of sixty times, removing the stopper and taking samples as the formulation flowed from the bottle, and measuring the salt content of each sample.

3.3.2. Results

FS-C showed better mixability than the cubic salt in terms of both mixing ease and resistance to separation. In the test of mixing ease, the mean deviation was 32% for FS-C and 41% for the cubic salt. In the separation resistance test, the mean deviation was 42% for the FS-C and 60% for the cubic salt.

3.3.3 Application trial

A performance trial was conducted to evaluate the potential for use with heme iron in the production of iron-fortified salt as a commercial product. Heme iron is recognised for its effectiveness as an iron supplement, because of its outstanding physiological absorption. Its extremely small particle size (approx. 15 μm), however, generally makes it difficult to obtain a satisfactory, stable mixture with conventional cubic salt. The colour contrast between

the black heme iron and the white salt, moreover, makes non-uniformity readily visible and unattractive to the potential user.

When FS-C was substituted for cubic salt, a uniform mixture was readily obtained and no visible separation occurred between the FS-C and heme iron particles.

3.4. Surface adhesion

Surface adhesion is particularly important in applications involving application of the salt to the surface of pastry, fish, or other food products.

3.4.1. Test method

Samples of the same salts as those used in the mixability test were poured from a height of 0.5 m onto a 0.2-m square sheets of #600 sandpaper placed on an adjustable slope [1]. For each salt, the slope of the sandpaper was decreased until the first observation of adhesion by the salt to the sandpaper, and the slope at that time (θ_s) was taken as the surface adhesion value.

3.4.2. Results

The θ_s values obtained for FS-C and the cubic salt were 31.5° and 29°, respectively, indicating that FS-C will adhere more readily to other surfaces.

3.4.3. Application trial

The trial was held in co-operation with a manufacturer of *senbei*, a form of rice cracker popular in Japan, made by frying rice-dough patties in oil containing dispersed salt particles (approx. 40 μm avg. particle size) to obtain the salted surface. Product yield was low with cubic salt due to its tendency for sedimentation in the oil, and vigorous stirring sufficient to maintain the necessary dispersion resulted in poor salt adhesion.

In the trial, with FS substituted for the cubic salt, dispersion in the oil was readily maintained and surface adhesion was uniform and stable. Adoption of FS in the commercial process has shown the same results, with a high product yield and with lower salt consumption further reducing the production cost.

3.5. Water retention

Water retention is a measure of the salt's capability to prevent the downward movement of a solution

under gravity, and thus its capacity for addition of solutions.

3.5.1. Test method

Bittern (7.5 wt% in terms of its water content, and thus in excess of the salt's water retention capacity) was added to a sample of the same salt as that used in the mixability test, and a column (50 mm inner diameter) was charged to capacity with the bittern laden salt, sealed, and left standing 8 days. The water content of the salt layer in the column was then measured, and taken as the water retention ratio.

The change in angle of repose was also determined, with addition of 1.0 wt% bittern in terms of its water content.

3.5.2. Results

The water retention ratios of the FS-C and the cubic salt were 4.0% and 1.3%, respectively, indicating that the capacity of FS-C for retention of bittern in terms of its water content is more than three times that of cubic salt.

The change in angle of repose following addition of the bittern was 10° (42° before, 52° after) with FS-C, and 20° (35° before, 55° after) with the cubic salt, indicating a larger fluidity change in the cubic salt.

4. CONCLUSION

The characteristics of FS are quite distinctive from those of the commonly marketed cubic salt, including faster dissolution, greater mixing ease and separation resistance, readier adhesion, and higher water retention, and an expanding range of applications is expected, to meet diversifying market preferences and requirements.

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