FACTORS AFFECTING THE PARTICLE SHAPE AND SIZE DISTRIBUTION IN THE CENTRIFUGAL SPRAYING OF SOAP

by

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INTRODUCTION

The pressure spray driers now widely employed by the soap industry for the production of soap powders have certain mechanical features which make them very efficient devices for this purpose. In these driers the process for conversion of liquid soap into dried powder is compressed into a single operation, and no further grinding or processing is necessary. Further, the capacity is high and unusually high rates of drying are obtained. The large extent of surface produced, the direct contact of the soap and drying medium, and the high velocity of the soap through the medium are all factors which tend to promote such high drying rates, and all are found in the spray drier.

Countering these advantages, the product produced has two notable faults. Particle size extends over a greater range than is desirable and the particles are somewhat irregularly shaped. The first of these is the more important, since fine particles lead to nasal irritation and detract from the marketing value of the powder. In addition, fine particles result in greater hygroscopicity and a tendency to cake, leading in turn to slower rates of dissolution. Irregularity of the particles, while not highly detrimental in itself, leads to the production of additional fine particles through the breaking off of minute projections during handling.

Besides retaining the advantages of spraying with nozzles the centrifugal type of atomizer is generally believed to yield a product of more nearly uniform particle size. It has an even higher capacity than the conventional pressure spray drier and the soap can be sprayed into the drying medium at very high velocities. These high velocities are of a decided advantage in that a mass of viscous material can thus be made to assume the shape which will give the least resistance to the passage of the particles through the drying medium -- a smooth, rounded particle free from undesirable projections.

The following report, then, is the result of an investigation to determine whether, by using centrifugal force, a typical high-grade soap base could be sprayed to produce a product containing spherically shaped particles not larger than 0.025 inch or smaller than 0.010 inch (passing a No. 30 testing sieve and being retained on a No. 60 testing sieve).

LITERATURE

The literature on spraying occasionally refers to the centrifugal type of atomizer and its possible applications, but it is believed that no previous article discusses the application or results of applying centrifugal force for the production of soap powders.

MATERIALS

The soap used for the investigation was supplied by the Procter and Gamble Company. It was a typical, white, high-grade soap base consisting of approximately 30 percent water and 70 percent soap solids. The equilibrium moisture content was about eight percent at room conditions. At temperatures just above freezing the soap became brittle and had little cohesion. Room temperatures softened the soap slightly so that it was cohesive and could be formed by hand with little difficulty. Near 180 degrees Fahrenheit the soap became soft enough to pour by agitation. Near the boiling point of water it was soft enough to flow. Over 212 degrees the contained water began to boil and escape from the viscous mass. When fluid this soap, like other soaps, exhibited non-Newtonian properties. At room temperature the specific gravity was near 1.027. The ease with which the soap went into solution increased with the water content. The soap dissolved in hot water and then cooled could jell several times its volume of water.

APPARATUS

The receptacle used to contain the soap to be sprayed consisted of a one-foot length of standard six-inch iron pipe sealed at both ends except for three openings in the top. To each of these openings was welded a half coupling. To one of the openings a 1/4-inch air line was attached. Through another opening a section of 1/4-inch standard iron pipe was introduced extending to within one inch of the bottom of the tank. The third opening was used to fill the tank with soap. This tank was submerged in a steam-heated, atmospheric, water bath.

Because constant air pressure alone would not give a constant rate of feed, a gear pump was connected by a short section of 1/2-inch copper tubing to the line which extended to the bottom of the tank. Between the pump and the tank was a brass, manually-operated, gate valve.

From the small gear pump, driven through a belt and pulleys by a 1/4-horsepower induction motor (for constant speed under changing loads), a copper line of the same diameter as before led to and then through a steam jacket and on to the center of the spray wheel (See Figs. 1 and 2).

Fig. 1. Feed mechanism.

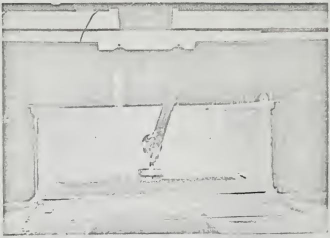

Fig. 2. Spray wheel and chamber.

At first the spray wheel was spun in the center of a metal box which was 29 inches square and 12 inches deep. The box was open so that the soap sprayed in it was subject to the temperature, humidity, etc., of the room. When it was found that photography alone indicated comparatively little regarding the condition of the particles produced, one of the sides of the box was removed so as to modify the apparatus as shown in the preceding picture.

The spray wheels, similar in design to that already shown in Fig. 2, were cast of an aluminum alloy. The top of a wheel when mounted was approximately four inches above the bottom of the chamber and the extended flat surface on which the soap particles to be analyzed were collected.

The wheel was driven from the bottom through a belt and pulleys by a 1/4-horsepower, 220-volt, A.C., series-wound motor capable of turning 10,000 revolutions per minute.

Temperature readings of the room and the soap in the tank were taken with mercury thermometers. For the temperature readings at the end of the copper tubing over the center of the spray wheel a Chromel-Alumel thermocouple was used extending about 1/4 inch up into the copper tubing.

To take pictures of the soap spray a 35-mm camera, using special film, was held 40 inches above the upper surface of the wheel. The light to expose the negative was a flash of less than 25/1,000,000 second produced by a G. E. Photolight (Figs. 2 and 3) held 31 inches on a 45-degree angle diametrically opposite from the camera.

The wheel speeds were measured with a Strobotac shown to the right of the Photolight in Fig. 3.

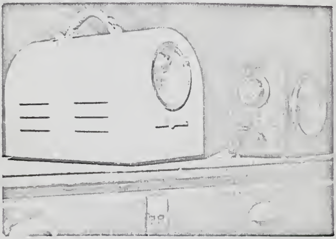

Fig. 3. Photolight and Strobotac.

PROCEDURE

The soap base was removed from the glass shipping containers and put into the tank set in the water-bath. Care was taken both by the company and the investigator to prevent the soap from drying and varying from the soap now being processed in the plant.

After the soap in the tank had reached a temperature of at least 190 degrees Fahrenheit, the pump and feed line up to the section enclosed by the steam jacket, were heated to about the same temperature. Compressed air regulated to 35 pounds per square inch was forced into the tank above the surface of the soap. The valve between the tank and the gear pump was then opened permitting the air to force the soap to the rest of the tubing at a constant rate into a container. After the hot soap had passed through the lines the pump was stopped and the feed line placed over the center of the spray wheel. Meanwhile, the spray wheel had been heated to about 200 degrees Fahrenheit by a gas flame directed at the under side. The wheel was then spun at the desired rate and the pump again started, forcing the soap onto the wheel.

As the wheel was spraying the soap the Strobotac was used to determine the rate at which the wheel was turning and how closely it maintained that rate under load.

Pictures of the spray were then taken as desired. After running for a minute or longer the soap was shut off and the wheel stopped. While waiting for the sprayed soap to solidify, weight-rate samples of the hot soap were collected from the end of the feed line.

After the soap had cooled enough a segment of the spray circle was marked on the collecting board and the sprayed soap particles laying within that area were swept up and collected Fig. 2.

This sample was put into a vacuum oven and heated at 160 degrees Fahrenheit for at least 16 hours while a vacuum of 30 inches was maintained so that the small and large particles would have the same moisture content. After being dried, cooled, and having reached an equilibrium moisture content by standing in the room for at least two days the sample was weighed and screened.

The screening consisted of manually shaking a number of sieves of the U. S. Series ranging from numbers 16 to 200 inclusive for an equal length of time.

In order to compare the effect of various factors on the shape of the soap particles, the portion of the sample that passed a number 30 and was retained on a number 40 screen as well as that which passed a number 100 and was retained on a number 120 screen was segregated and marked to be photographed later.

PRECISION OF MEASUREMENTS

The temperature of the soap falling onto the spray wheels was controlled between 187 and 200 degrees Fahrenheit. The temperature of the air into which the soap was sprayed varied between 80 and 90 degrees Fahrenheit.

The wheel speeds as measured by the Strobotac (checked against the current alternations) varied less than two percent during a run. The maximum variation occurred at the higher speeds and heavier loads.

Measurements of the apparatus were within the tolerance allowed on the tools used to produce it. In general the accuracy is obvious where it is not given. The probable accuracy of feed rates is given the first time the feed rate is mentioned.

Two different runs under the same conditions would yield a screen analysis of the product varying not more than two percent, usually in the same direction, for the cumulative weight percent retained on a given screen. Usually the variation was less.

OBSERVATIONS

Early attempts to effect spraying by forcing melted soap on the center of a flat upper surface of a spinning wheel were unsuccessful, for the friction between the wheel and the soap was too small to impart any velocity to the soap. As a result the soap almost fell over the edge of the wheel in large masses. A variation (Fig. 4) in the design of the wheel was no better. The shadows showing the particles in flight and the soap on the bottom of the box indicate that little or no spraying has occurred. The wheel was turning in a counter-clockwise direction.

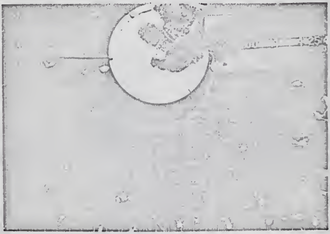

Fig. 4. (a) Soap spraying.

The scale of the picture and all similar pictures hereafter shown is one inch on the picture equals six inches actual size. The number immediately to the right of the wheel is the number of revolutions per minute at which the wheel is revolving. The rest of the numbers are of interest to the investigator only.

Another wheel having 1/4-inch high ridges extending radially from a hole in the center affected comminution but the air turbulence was very great and some of the soap would jump over the ridges, after soap had stuck to them, and drop into the box without first having attained enough velocity to be broken up while passing through the air. Therefore, wheels were used having closed channels or radial holes cut into the side of the wheel in the plane of motion and meeting a hole drilled into the center of the wheel.

Fig. 5. (b). Soap spraying.

Figure 5, a picture of a six-inch diameter wheel with four 3/8-inch radial holes meeting a 1/2-inch round hole 5/8 inches deep at the center, shows that with a feed rate of between 0.66 and 0.82 pounds per minute the soap stream remains intact for some distance from the wheel.

Figure 6, a picture of the same wheel and the same feed conditions obtained as in Fig. 5, shows that at a higher rate of revolution the soap stream disintegrated closer to the wheel.

Fig. 6. (c). Soap spraying.

Figure 7, a picture of the same wheel, shows that with all other conditions being the same with the exception that only one spray tube is operating and is delivering four times the soap per cross-sectional area as Figs. 5 and 6 (the wheel is revolving at a rate of 10,000 r.p.m.), the soap stream travels farther before complete disintegration occurs.

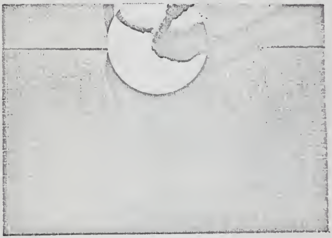

Fig. 7. (d). Soap spraying.

Figure 8, a picture of a wheel having twelve 1/8-inch round radial holes and revolving at the same rate as the wheel in Fig. 7, shows that for the same total rate of feed but a lesser rate per cross-sectional area of opening at the periphery the soap stream disintegrated closer to the wheel.

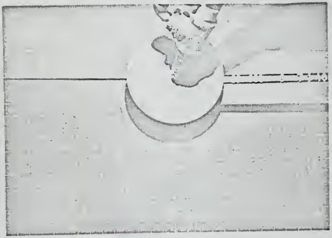

Fig. 8. (e). Soap spraying.

The phenomena discussed above will be referred to later in the light of other observations.

Wheels with radial rectangular channels were also used and showed the same effect.

To decrease the horizontal travel of the soap particles a wheel was used similar to the impeller in a centrifugal pump and revolved in the same direction. The same results could be obtained with the above wheels, (excluding Fig. 4) if the wheel were revolved to give the same exit velocity of the soap.

WHEEL CAPACITY VERSUS SPEED

The wheel shown in Figs. 5, 6, and 7 being six inches in diameter with four 3/16-inch radial holes meeting the bottom of a 1/2-inch round 5/8-inch deep hole in the center, would not take all of the melted soap delivered to it at a rate of 0.74 pounds per minute when revolving at a rate of less than 3,000 revolutions per minute. Below 3,000 r.p.m. some of the soap would spill over the sides of the center feed hole, roll over the edge of the wheel and fall to the bottom of the box without being sprayed. This fact will be referred to later in the section discussing correlation of the data. This same wheel, however, accepted without difficulty soap fed to it at a rate of 5.5 pounds per minute when it was revolving at a rate of 10,000 revolutions per minute.

A wheel three inches in diameter with four 3/16-inch radial holes plugged at the periphery for 1/4-inch leaving a 3/64-inch opening in the center of the plug, barely accepted 1.4 pounds of melted soap per minute when revolving at a rate of 17,000 revolutions per minute.

From these points an estimate can be obtained regarding the capacity of wheels of different design. A basket type wheel with sufficient openings could accept an enormous amount of liquid soap.

This relationship between feed rates, wheel design, and wheel speeds has an effect upon the sprayed-soap particle-size distribution, to be shown and discussed later.

When the soap was fed to the revolving wheels at a low weight rate per unit cross-sectional area of spray openings or when the feed tube was held high above the plane of the line of spray tubes at the bottom of the entrance hole, the soap leaving the feed pipe would touch the wheel, be broken off, and forced out of the spray holes -- a continuing process resulting in intermittent spraying. This effect was not investigated further. Up to a certain point this low rate can give smaller particles. The same phenomena occurred when the entrance hole was enlarged so as to increase the capacity of a slowly spinning wheel. Of course, the high pressures and strain developed at high wheel speeds must be carefully considered in the wheel design.

PARTICLE SIZE DISTRIBUTION

After deciding that more could be learned about the particles in the sprayed product by means other than photographing them as they left the spinning wheels, one side of the box surrounding the spray wheel was removed and a horizontal platform was built four inches below the plane of the spray to catch the sprayed particles. The data hereinafter presented was obtained by screening the soap particles dispersed within the segment of the part circle formed by the sprayed particles Fig. 2.

After numerous attempts to obtain a straight line with the data in order to facilitate correlation, it was decided that a cumulative percent versus linear screen opening approached a straight line with sufficient accuracy. Then, because any change in variables only changed the slope of the straight line and the lines appeared to converge at point, a point of convergence was chosen. All straight lines could be drawn from this point and still represent, within reasonable limits, all the experimentally determined points. Hereafter, all straight lines on the particle size distribution graphs radiate from that chosen point. This radiation and straight line correlation introduces an error in the smaller particle size indicated, but even so, within the range investigated the maximum variation introduced, and with particles passing a U. S. Series sieve number 200, this error is less than four percent. Since the zero-particle size is above the point of convergence, continuing one of the lines past the 200-mesh screen leads to values void of significance. A characteristic of this type of plot, is that it fails near the zero percent. Perhaps a plot using a probability other than normal would be better, but this is the only type of probability graph paper commercially available.

The first graph, Fig. 9, following this page represents the experimental data obtained with the wheel already shown in Figs. 5, 6, and 7 (See the section headed Precision of Measurements for the experimental conditions and the probable amount of variation.)

The second graph, Fig. 10, is taken from experiments carried out under identical conditions except that the wheel used is the same as that shown in Fig. 8. This wheel produced greater dis-

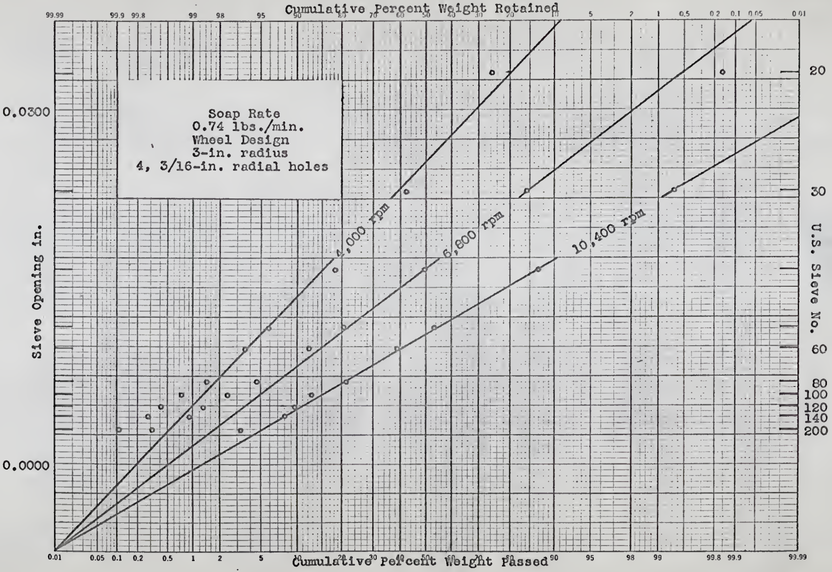

Fig. 9. Particle size distribution.

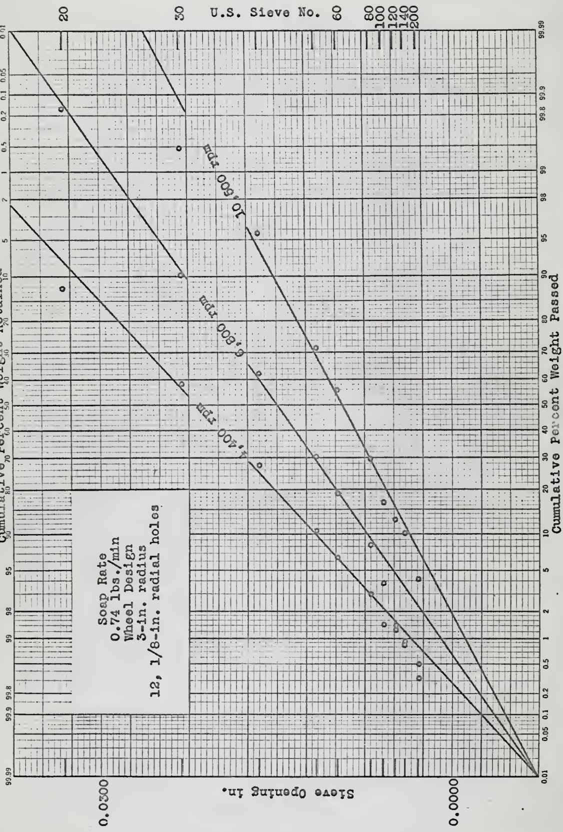

Fig. 10. Particle size distribution.

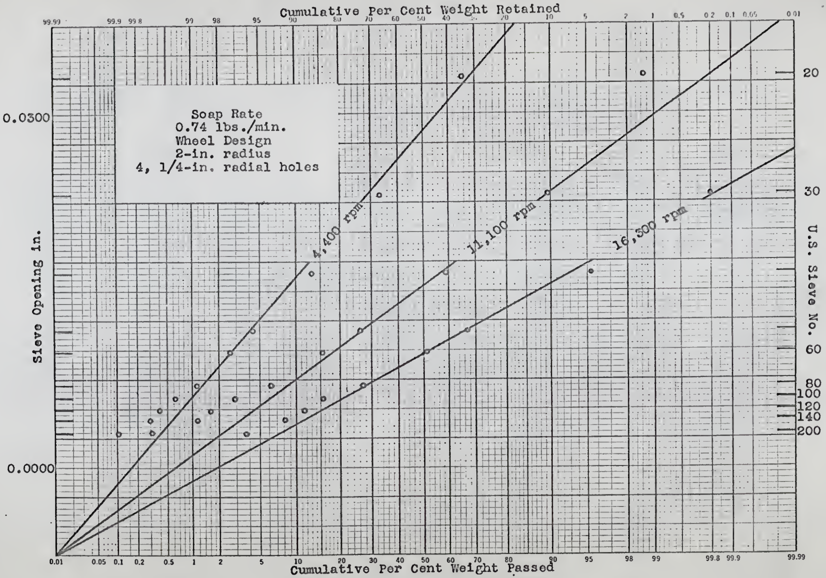

Fig. 11. Particle size distribution.

integration for the same angular velocity - a fact discussed later.

The third graph, Fig. 11, from experiments again under the same conditions, shows that the straight line distribution holds and that for the same angular velocity the smaller wheel gives greater disintegration than do the larger wheels - a fact also discussed later. Realizing that the same results could be obtained by any of the wheels, experiments were conducted using different feed rates.

Figure 12 shows the results obtained with the same wheel used to obtain the data for Fig. 9, when the feed rate was increased to between 1.33 and 1.39 pounds per minute. Here again the typical distribution was obtained, the only change being that the slope of the straight line drawn through the experimentally obtained points was increased for the same angular velocity.

Figure 13 shows the results obtained with the same wheel used to obtain the data for Fig. 10, when the feed rate was increased to 1.36 pounds per minute. Again the slope of the straight line increased.

Figure 14 shows the results obtained with the same wheel used to obtain the data for Fig. 11, when the feed rate was increased to 1.36 pounds per minute. The same increase occurred.

The high angular velocity was used to obtain particles more nearly spherical than a low angular velocity would give. Figure 15 was constructed to correlate the data already shown with other data not given here. It was derived in the following

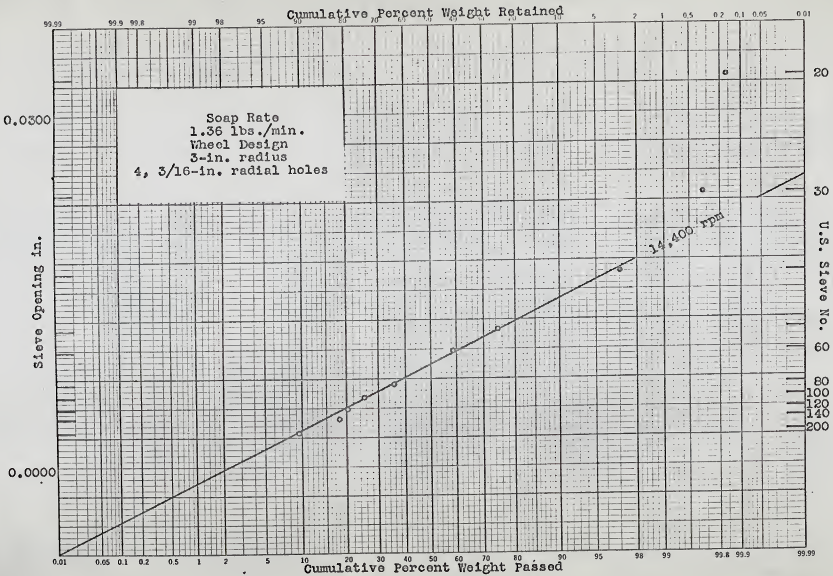

Fig. 12. Particle size distribution.

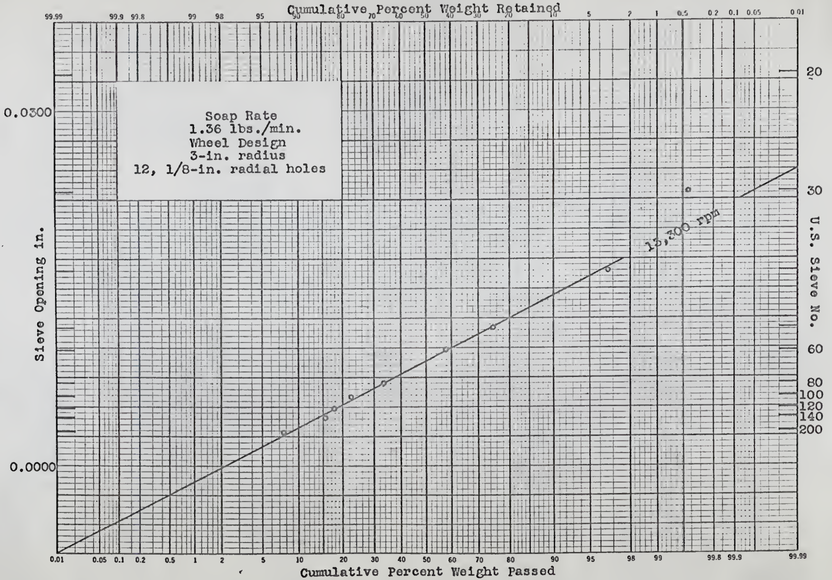

Fig. 13. Particle size distribution.

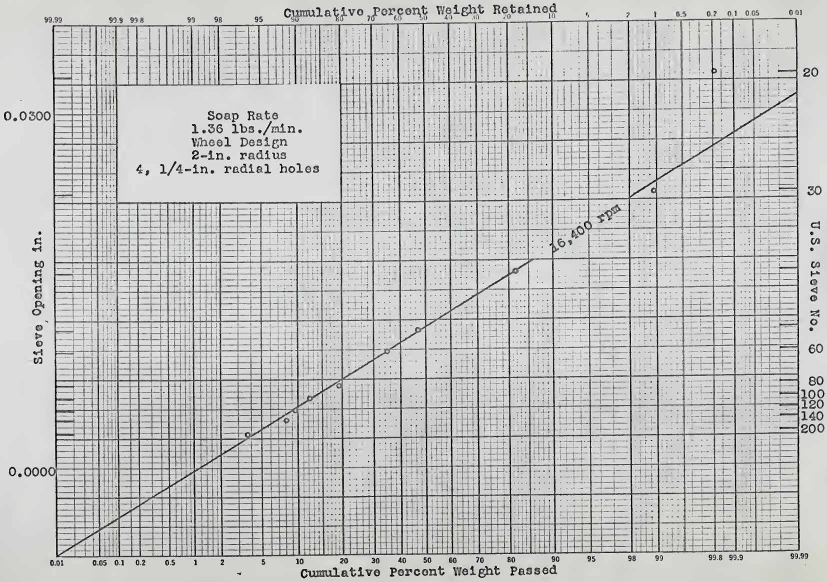

Fig. 14. Particle size distribution.

manner according to the line of reasoning given below. This correlation is the result of an attempt to predict quantitatively the magnitude and direction a given change in feed rate and angular velocity would produce in the particle size distribution. It must be remembered that the purpose of this investigation was to obtain particles within the desired size range rather than to study the effect of variables.

Consider, for example, a small bead in one of the tubes of the spray wheels previously described. Neglecting and friction we find that either from force relationships or solving the second differential equation of the distance the bead travels along the tube with respect to time that the following equation is obtained:

$$V_{final}^2 - V_{initial}^2 = \omega^2 (x_1^2 - x_0^2)$$

where

V_{final} = final velocity of the bead at the periphery

$V_{initial}$ = initial velocity of the bead

ω = angular velocity in radians

x_1 = distance from the center to the periphery

x_0 = distance at which the bead starts

Assuming that the initial velocity of the soap is negligible and that x_0 is so small as to have negligible effect for this purpose we obtain

$$V_{final} = \omega x_1$$

or when the wheel is revolving at a constant rate, no angular acceleration, the component of the velocity along the radius just as the soap leaves the wheel is equal to the component of the velocity along the tangent. Consequently, the actual velocity of the soap as it leaves the wheel is $\sqrt{2}\, r\omega$. Checking this assumption with pictures like Figs. 5 and 7 indicate that the assumption of negligible friction etc., was justifiable.

Figure 15 was constructed as follows. From Fig. 9 the point of intersection of the straight line drawn through the points and the size of the number 30-mesh screen (from this point and the point of convergence chosen for the particle distribution lines all other points could be estimated) was plotted against the radius in inches times the revolutions per minute. Since the spray holes were radial, to convert to velocity of particle leaving the periphery each value must be multiplied by a factor of 8.88, ($\sqrt{2} \times 2\pi$), considering as before negligible friction, etc. The velocity of the exit particles from a wheel of any design can be determined from pictures or calculations. The lowest radial line on Fig. 15 then represents the change in the point of intersection versus speed when other conditions are constant. The additional points are from experiments not included in this paper.

The next to the lowest line was obtained from the points of intersection of Fig. 11, not 10, and other runs. This procedure was followed for the rest of the lines up to the two uppermost.

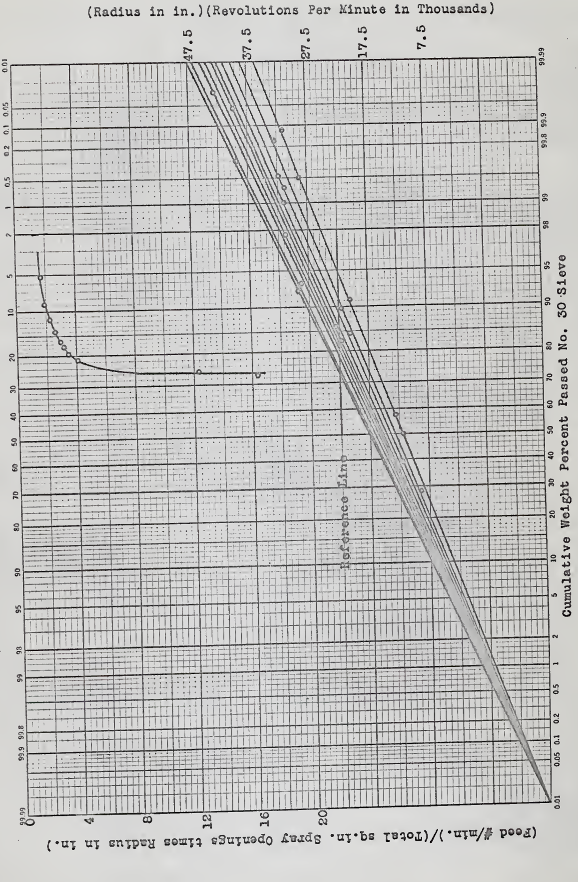

Fig. 15 Correlation diagram.

The point of intersection again is a point chosen by the investigator when it appeared that all the points representing a straight line converged at that point. Again, this leads one to believe that a stopped wheel will give a certain percentage of particles passing a number 30-mesh screen, here one is referred to page 14. The point of transition where the solid lines might be changed to dotted to indicate failure of this correlation has not been determined.

The plot indicates that the particle size is inversely proportional to the velocity of the soap particle as it leaves the wheel. It also indicates that the particle size increases with increase in feed per cross-sectional area of spray openings.

Another indication is that for the same amount of soap fed to the wheel per cross-sectional area of spray tube opening, a wheel of small radius will give finer particles for the same tangential velocity. This indicates that a breaking up of the soap occurs inside the spray tubes. Perhaps it can be explained by the fact that for the same tangential velocity (speed at periphery) the acceleration, consequently the force, along the radius is inversely proportional to the radius. That then is the basis for the correlation shown by the curved line at the upper part of Fig. 15.

A straight line was drawn arbitrarily through the line representing the 22.5 radius times the revolutions per minute line and is labeled Reference Line.

This intersection was plotted against the weight rate of soap in pounds per minute divided by the total square inches of tubular opening leading to the periphery, a correlation using something analagous to a hydraulic radius might serve. Because of the greater acceleration obtained in the wheel of lesser radius, this term was divided by the radius. (The denominator in this case then becomes volume of tubes, but it cannot be interpreted as such for further application of this relation, as will be mentioned later).

Since these radial lines began to get closer together and the slope of the plot of these lines with the Reference Line versus the relationship explained above began to increase, it was decided to increase the soap rate to about five pounds per minute to get the maximum amount of particles in the sprayed product between the desired range and still have particles as close to spherical as the high velocity of soap leaving the wheel had previously produced.

Figure 16 is a result of this run using the six-inch wheel and a feed rate between 4.6 and 6.2 pounds of melted soap per minute. The soap temperature, room temperature, etc., was the same as in the runs previously described. Another run was made using the six-inch wheel with twelve 1/8-inch holes and gave the points for Fig. 17. Again the points obtained followed the straight line.

The intersection of the straight lines drawn through the points and the 30-mesh particle size were plotted on Fig. 15.

The near coincidence of these two lines and the sudden drop produced in the upper plot indicated that at this feed rate per

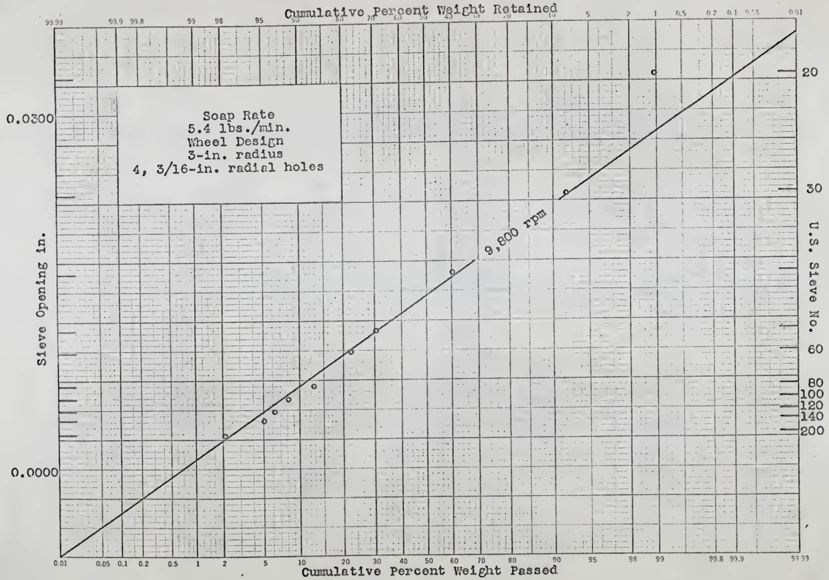

Fig. 16. Particle size distribution.

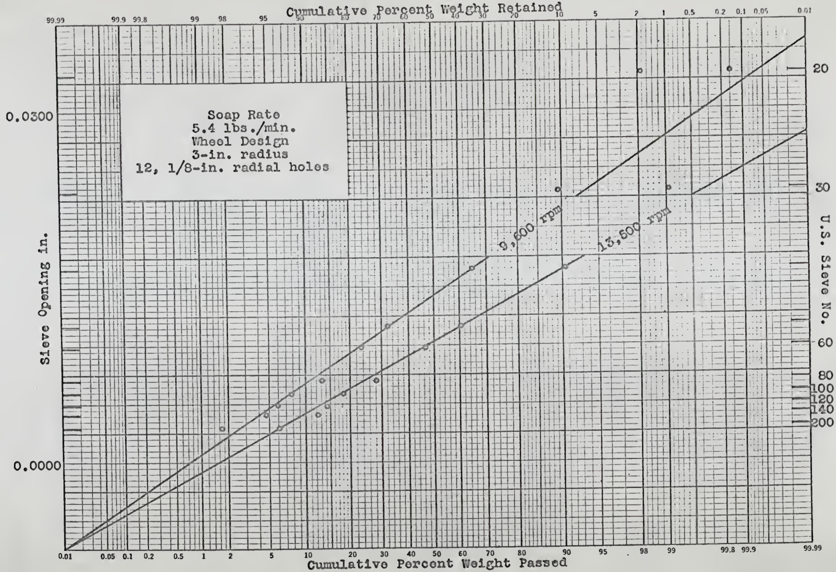

Fig. 17. Particle size distribution.

cross-sectional opening the effect of the rate of feed was small compared to the effect of the velocity at which the soap left the wheel. Perhaps this effect could be compared to a fireman's hose where the dispersion of the water is proportional to the pressure up to the maximum effect and not upon the cross-section of the stream. In other words the particles leaving the tubes were of the same diameter as exit spray holes and not smaller than those in the case of lower feed rates, as Figs. 6 and 8 show. Figure 7 indicates that the tube is about full for the higher rate. (The scale of the picture is one inch equals six inches).

Although more runs could certainly be made at these higher feed rates it would be expected that here also the straight line relation between particle size and velocity would hold, for it has been found that for pressure nozzles the drop size is approximately inversely proportional to the square root of the pressure. Furthermore, complete conversion from pressure head to velocity results in the expression that the velocity is proportional to the square root of the pressure. Then, for high feed rates a centrifugal wheel is no better than a nozzle.

The upper radial line in Fig. 15 then indicates that the action of the particle passing through the air is the only force tending to disintegrate the soap. The lower lines indicate that a breaking up is occuring within the wheel, and therefore smaller particles were obtained with the same wheel revolving at the same speed. This latter effect, however, appeared to have no effect on the particle size distribution.

A six inch wheel was used which had radial rectangular slots 5/8-inch deep and 3/16-inch wide but this wheel also gave the straight line particle distribution. This wheel with a feed rate of 0.74 pounds of soap per minute was not as effective in breaking up the particles as Fig. 15 indicated it might be. It was better than a high rate for the round spray openings but not so good as the wheels previously described when the same amount of melted soap and angular velocity was used. The wheel was not used in subsequent runs because it gave no improvement towards the particle size range desired.

A wheel of design similar to that of an impeller in a centrifugal pump and run in the same direction was used so as to decrease the horizontal distance the particles travelled through the air. No improvement was noticed for the particle size distribution and the slight change in particle travel for the same size and shaped particle made this wheel also unsatisfactory.

The next graph, Fig. 18, drawn from data obtained with two three-inch wheels. Both wheels had the same size entrance hole in the center as all the other wheels. The line drawn to the right was obtained with the wheel that had four 3/16-inch radial holes leading to the periphery but the holes were stopped at the outer end with a 1/4-inch long plug in the center of which was a 3/64-inch hole -- equivalent to the opening in a number 16 screen. The lower radial line was obtained with a wheel of the same diameter except that the spray holes leading to the periphery were 3/8-inch in diameter. The feed rate in both runs was 1.36 pounds per minute.

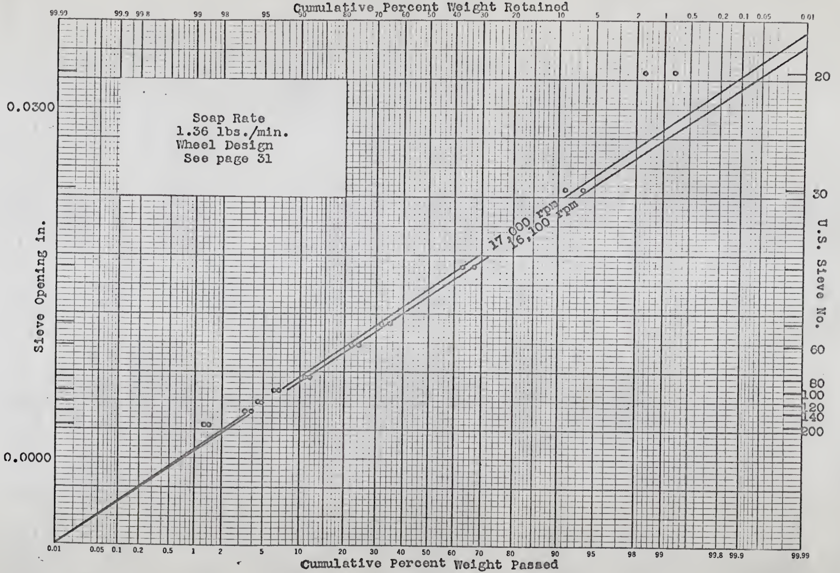

Fig. 18. Particle size distribution.

In the first case mentioned an orfice effect must have assisted in breaking up the soap particles, for when correlated as before the wheel gave smaller particles than the tangential velocity would have indicated for such high concentration of soap per cross-sectional area of spray holes. Pictures of the difference in particles obtained in each case are shown later.

In the light of other runs the effect of disintegration within the wheel must also have occurred. The wheel also was more effective than the six-inch wheel with channels for the same peripheral velocity and soap rate unit cross-sectional area.

PARTICLE SHAPES

The following pictures are of particles separated from the total sample of soap collected by screening in the manner described in the first part of the report. The pictures are five times actual size. The background is ordinary millimeter graph paper making the actual size of each small square 0.1 millimeter or 0.03937 inches on a side -- the opening in a number 18 U. S. sieve. The series of pictures show that the soap at a given temperature, sprayed into air at a given temperature, will produce particles according to the speed at which the soap leaves the wheel. The size of the wheel, size or shape of spray openings on the periphery, or the flow rate of soap through the openings at the periphery seems to be small compared to the effect of the speed at which the soap leaves the wheel. The higher the velocity the more nearly spherical is the final product, and this effect is more noticeable on the larger particles than on the smaller due to the fact, perhaps, that the larger particles naturally travel farther thereby giving air a longer time to act on the particle. Furthermore, the small particles having a lower total heat content and more surface, to lose this heat and the dissolved water, solidify faster to become more rigid and thus are more resistant to the tendency of fluid particles to assume the shape offering the least resistance to their passage through the air. Of course, spray cooling was employed and it must be expected that a heated chamber will produce particles more nearly spherical with lower soap speeds, and also smaller particles, if drying does not occur too quickly, raising the melting point and with it the rigidity of the expanded particle. Spraying into relatively cold air as was done here, the sample collected had, on the average, already lost approximately 50 percent of its original moisture content.

Figure 19 is that part of the sample retained on a 40 and passing a 30-mesh sieve from the run represented by the 4,400 r.p.m. line on Fig. 10. The velocity of the soap stream, 9,800 ft/min., calculated using the formula $\sqrt{2}\ r\,\omega$ - for purposes of comparison - is the velocity of the soap stream just as it left the periphery of the wheel.

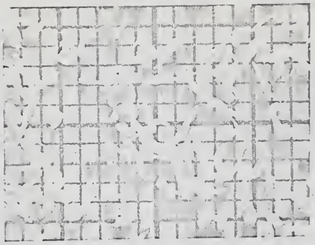

Fig. 19. (a). Soap particles.

Figure 20 is of the same size particles obtained from the run represented by the 11,100 r.p.m. line on Fig. 11. The velocity of the soap stream as calculated above was 16,400 ft./min.

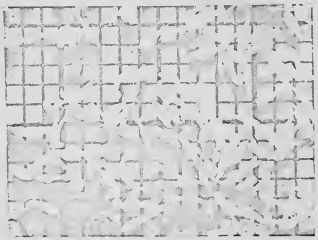

Fig. 20. (b). Soap particles.

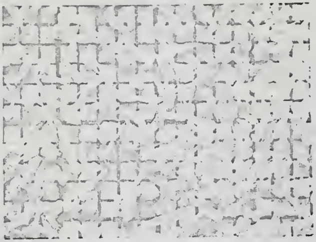

Fig. 21. (c). Soap particles.

Figure 21 is of the same size particles obtained from the run represented by the 16,300 r.p.m. line on Fig. 18 - the three inch diameter wheel with 3/8-inch openings. The velocity of the soap was 17,900 ft./min.

Fig. 22. (d). Soap particles.

Figure 22 is of the same size particles obtained from the run represented by the 17,000 r.p.m. line on Fig. 18. The velocity of the soap was 19,200 ft./min.

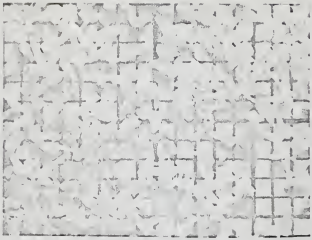

Fig. 23. (e). Soap particles.

Figure 23 is of the same size particles obtained from the run represented by the 9,800 r.p.m. line on Fig. 16. The velocity of the soap was 21,700 ft./min.

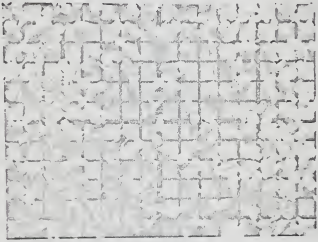

Fig. 24. (f). Soap particles.

Figure 24 is of the same size particles obtained from the run represented by the 10,500 r.p.m. line on Fig. 10. The velocity of the soap was 23,000 ft./min.

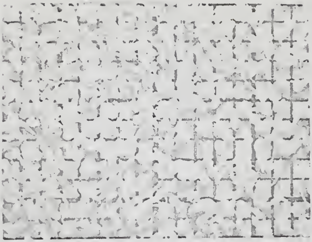

Fig. 25. (g). Soap particles.

Figure 25 is of the same size particles obtained from the run represented by the 13,500 r.p.m. line on Fig. 17. The velocity of the soap was 30,400 ft./min.

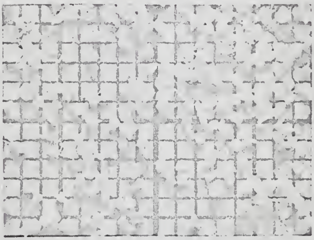

Fig. 26. (h). Soap particles.

Figure 26 is of the same size particles obtained from the run represented by the 14,400 r.p.m. line on Fig. 12. The velocity of the soap was 32,000 ft./min.

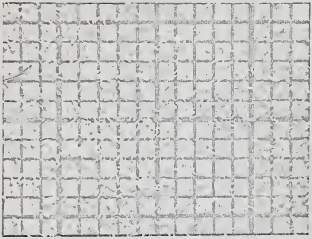

Fig. 27. (i). Soap particles.

Figure 27 is of the particles whose size range from 0.0059 inch to 0.0049 inch in the smallest dimension or the particles passed a 100-mesh screen and retained on a 120-mesh screen. The particles are from the same run as Fig. 19. Again the pictures are five times actual size.

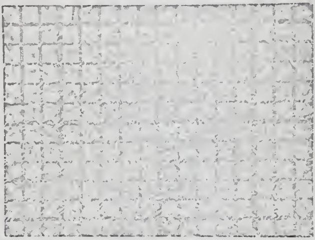

Fig. 28. (j). Soap particles.

Figure 28 is of the same size particles as Fig. 27. The particles were obtained from the same sample as Fig. 21. It appears that large tubes or channels give a slightly longer particle for a given diameter than do the smaller tubes. A thorough study to verify this has not been made, however.

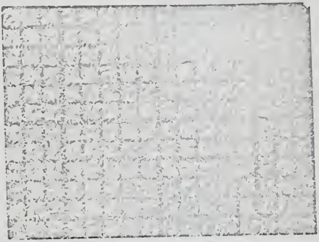

Fig. 29. (k). Soap particles.

Figure 29 is of the same size particles obtained from the same sample as Fig. 22.

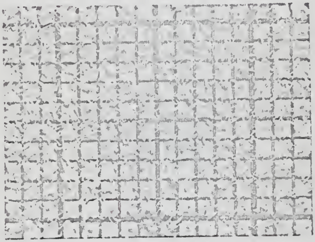

Fig. 30. (l). Soap particles.

Figure 30 is of the same size particles obtained from the same sample as Fig. 23.

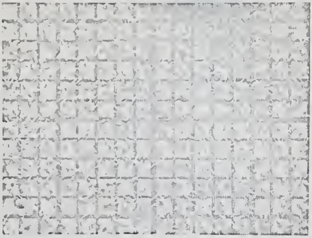

Fig. 31. (m). Soap particles.

Figure 31 is of the same size particles obtained from the same sample as Fig. 25.

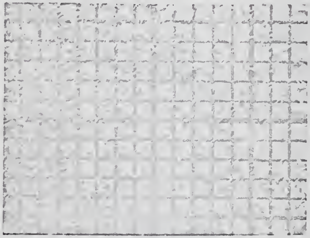

Fig. 32. (n). Soap particles.

Figure 32 is of the same size particles obtained from the same sample as Fig. 26.

These rod-shaped particles, produced to a greater or lesser degree depending upon the experimental conditions, have, of course, an effect on the particle-size distribution obtained by screening, for it is certainly improbable that all particles of the same diameter are going to fall on the screen in such a way as to ultimately fall into the particle size to which it belongs. However, it is believed, and the preceding pictures taken at random appear to support this opinion, that the particle size distribution, though not exact, is accurate enough to permit comparisons. The occurrence of rod-shaped particles is especially noticeable in the regions of low exit velocities and with the smaller sized particle.

Although actually the size must go to zero percent at zero size the variation from the straight line might appear greater than is actually the case. However, the larger number of small particles tend to shift the analysis towards the desired accuracy.

EFFECT OF TEMPERATURE

Soap sprayed at temperatures slightly lower than 180 degrees Fahrenheit produced particles somewhat stringy for the same exit velocity. The size distribution followed the straight line and the only difference appeared to be that the slope of the line increased i.e., larger particles were produced for the same number of revolutions per minute with the same wheel. It is not known whether points would fall on a straight line when correlated with Fig. 15.

EFFECT OF MOISTURE CONTENT

When water was added to the soap so that the moisture content was increased to approximately 40 percent, at a feed rate of 2.2 lbs./min. using the six-inch diameter wheel with the 12 radial holes revolving at 9,600 r.p.m., the same particle size distribution was obtained as when 1.1 lbs./min. of soap containing 30 percent water was fed to the same wheel revolving at 10,450 r.p.m. An increase in water content decreased particle size and gave particles more nearly round, other conditions be- equal just as temperature increase did. However, no change from the particle size distribution was observed in either case. Both water content and temperature decreased viscosity in the same direction, but the magnitude of the effect of either was not determined.

PARTICLE TRAVEL

The lower wheel speeds which produced the largest particles sent the soap spray considerable farther horizontally than did the higher wheel speeds. For example, the largest particles, leaving the wheel at a calculated velocity of 3,800 ft./min. from the run represented by the 4,000 r.p.m. line on Fig. 9 were thrown about 15 feet radially while dropping but four inches. Particles from the run represented by the 14,400 r.p.m. line, although having left the wheel at a calculated velocity of 32,000 ft./min. travelled about nine feet radially while dropping the four inches. Because of the disintegration of the soap stream at high exit velocities, the particles travelled the farthest for the lowest exit speeds and the shortest for the highest. The energy imparted to the soap by the revolving wheel was used to create smaller particles rather than displace a larger one a greater distance at the higher exit velocities. Because the particle size is not a function of the exit velocity alone but also of any other variable that will decrease the resistance of the substance to form small particles, the travel of a particle can be of true value only when the magnitude and effect of these other variables is also given. The distances given above are the observed values under the conditions of the experiment already described in another section of this report.

SUMMARY

Within the range of experiments the maximum weight percent of soap particles not larger than 0.025 inch nor smaller than 0.010 inch (passing a No. 30 testing sieve and being retained on a No. 60) that could be obtained by centrifugal spraying alone was 70 percent. This maximum could be obtained in every way attempted but it could never be exceeded. Other maximums are as follows:

U. S. Sieve No.		Maximum weight percent between sizes given
-20	+30	40
-30	+40	34
-40	+50	33
-50	+60	16
-60	+80	26

Other maximums can be obtained from any of the particle size distribution graphs in the report. They cannot, however, be obtained by adding the numbers given in the table above. For example, the maximum amount attainable between the 30 and 50 sieves is not 67 but 61 percent as the graphs show.

The shape of the soap particle is a function of the speed at which the soap stream leaves the wheel. The higher the exit velocity of the soap the closer the particles approached a spherical shape.

At low feed rates per cross-sectional area of spray tubes or channels leading to the periphery, disintegration of the soap stream begins in the tubes or channels and continues during the time the particle travels through the drying medium. This effect, however, does not change the type of particle size distribution.

The higher the feed rate per cross-sectional area of spray tubes or channels the larger will be the particles, other conditions being equal, up to a certain maximum.

The particle size is inversely proportional to the velocity of the soap leaving the spray wheel. Variables decreasing the viscosity of the soap decrease the particle size for a given exit velocity.

Like water, there is a maximum distance soap particles can be thrown. Increasing the velocity above that corresponding to this maximum increases the atomization of the particles and results in a shorter distance of travel.

The literature on spraying occasionally refers to the centrifugal type of atomizer and its possible applications, but it is believed that no previous article discusses the application or results of applying centrifugal force for the production of soap powders.

ACKNOWLEDGMENT

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