FERTILIZER GRANULATION

Effect of Particle Size of Potassium Chloride on the Granulation of Mixed Fertilizer

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Evaluation of the particle-size effect of initial materials on fertilizer granulation is essential to the establishment of particle-size standards for raw materials entering the process. The particle-size effect of potassium chloride on granulation efficiency of a mixed fertilizer containing 5% nitrogen, 8.7% phosphorus, and 16.6% potassium (5–20–20 grade) was evaluated on the basis of behavior of the mixture in processing, product yield, and nutrient uniformity in the product. Increasing the particle size of the potassium chloride benefited processing of the mixture and increased the yield of granular product but hindered particle growth and distribution of nutrients in the product. Greatest over-all efficiency of the granulation process was indicated with the use of raw materials in the 14- to 100-mesh particle-size range in which a large proportion of the potassium chloride was in the 48- to 100-mesh range.

The effect of particle size of raw materials on granulation efficiency is of concern to the fertilizer manufacturer, particularly in view of recent efforts to establish standards for particle size (*1, 3, 5, 7*). Lack of uniformity in procedures for classifying particle size (*5*) has tended to obscure interpretation of initial particle-size effects on granulation. It was shown in a preceding paper (*8*) that triple superphosphate, subjected to ammoniation-granulation in the laboratory, exhibited characteristic variation in granulation efficiency as a result of predetermined variation in particle size of the initial material. Variation in particle size of potassium chloride used in preparing granular mixed fertilizer by conventional non-slurry methods is of particular concern. Mixtures that are low in nitrogen and high in potash content, such as one containing 5% nitrogen, 8.7% phosphorus, and 16.6% potassium (5–20–20 grade), are difficult to granulate with the use of fine potassium chloride. Mixtures of higher nitrogen content—for example, one containing 10% nitrogen, 4.4% phosphorus, and 8.3% potassium (10–10–10 grade)—appear to granulate well with fine potassium chloride (*4–7, 9, 10*). It is generally recognized that coarse potassium chloride used in low-nitrogen, high-potassium grades improves the rolling action of the mixture in rotary equipment and the yield of on-size product (*6, 9, 10*). However, it may interfere with uniformity of nutrients in the granular product (*4, 6*).

Data on the effect of particle-size distribution of potassium chloride on granulation efficiency of mixed fertilizer containing 5% nitrogen, 8.7% phosphorus, and 16.6% potassium (5–20–20 grade) are reported in this paper.

Formulation

The mixed fertilizer was formulated with the following commercial materials: anhydrous ammonia, ammonium sulfate, ordinary and triple superphosphates, and potassium chloride (Table I). The N, P, and K contents were determined by official AOAC procedures (*2*). The superphosphates were typical run-of-pile materials, and the potassium chloride was the red, crystalline material frequently referred to as "regular."

Particle-Size Distributions in Initial Mixture. Each solid material used in the mixtures was sized to give seven fractions: 14–28, 20–35, 28–48, 35–65, 48–100, 65–150, and 100–200 mesh, respectively. These fractions were used to prepare 12 mixtures characterized by four particle-size distribution patterns—standard, coarse skewed, normal, and fine skewed—and three particle-size ranges—coarse (14–100 mesh), medium (20–150 mesh), and fine (28–200 mesh).

Table II shows the design of the four particle-size distribution patterns for mixtures in the coarse particle-size range, referred to in this study as "mixtures 1c to 4c." Corresponding mixtures having identical distribution patterns were prepared in the medium and fine particle-size ranges (footnote *b*, Table II), "mixtures 1m to 4m" and "mixtures 1f to 4f," respectively. The particle-size distribution patterns within each size range are designated as standard, coarse skewed, normal, and fine skewed. The standard pattern for mixture 1 in each size range contained substantially equal

Table I. Formula of Fertilizer Containing 5% Nitrogen, 8.7% Phosphorus, and 16.6% Potassium

(5–20–20 grade)

Ingredient		Weight, Lb.	Plant Nutrients,[a] Units		
Kind	Analysis, %		N	P	K
Anhydrous ammonia	82.2 N	90	3.70		
Ammonium sulfate	20.5 N	133	1.36		
Triple superphosphate	21.34 P (48.9 P_2O_5)	612		6.53 (14.96)[b]	
Normal superphosphate	8.96 P (20.5 P_2O_5)	503		2.25 (5.16)	
Potassium chloride	50.2 K (60.5 K_2O)	662			16.61 (20.03)[b]
Total	...	2000	5.06	8.78 (20.12)	16.61 (20.03)

[a] Product analyses showed nutrient content to be N 4.71, P 9.11, and K 16.93% (P_2O_5 20.88, and K_2O 20.39%). [b] Values in parentheses are oxide equivalents.

Table II. Design of Particle-Size Distribution Patterns

Solid Materials Used in Formulating Mixture						
		Proportion Present in Size Fraction, %[a]			Particle Size Distribution	
Mixture	Kind of material	14–28	28–48	48–100	No.	Name
	Superphosphate and ammonium sulfate	22	21	22		Standard
	Potassium chloride	12	12	11		Standard
1c[b]		34	33	33	1	Standard
	Superphosphate and ammonium sulfate	22	21	22		Standard
	Potassium chloride	25	5	5		Coarse skewed
2c[b]		47	26	27	2	Coarse skewed
	Superphosphate and ammonium sulfate	22	21	22		Standard
	Potassium chloride	5	25	5		Normal
3c[b]		27	46	27	3	Normal
	Superphosphate and ammonium sulfate	22	21	22		Standard
	Potassium chloride	5	5	25		Fine skewed
4c[b]		27	26	47	4	Fine skewed

[a] Tyler standard-mesh sieves used in fractionating materials. [b] c signifies coarse range of particle size (14–100 mesh) in which mesh fractions are 14–28, 28–48, and 48–100. In a second series of four mixtures, 1m to 4m, m signifies medium range of particle size, 20–150 mesh, in which mesh fractions are 20–35, 35–65, and 65–150. In a third series, 1f to 4f, f signifies fine range of particle size, 28–200 mesh, in which mesh fractions are 28–48, 48–100, and 100–200. Corresponding mixtures in coarse, medium, and fine particle-size ranges have identical particle-size distribution patterns.

Table III. Initial Average Particle Size of the Mixture

	Initial Av. Particle Size of Mixtures in Size Range, Mm.[a]		
Mixture Pattern No.	Coarse (c) (14–100 mesh)	Medium (m) (20–150 mesh)	Fine (f) (28–200 mesh)
1	0.417	0.295	0.208
2	0.518	0.365	0.259
3	0.417	0.295	0.208
4	0.325	0.231	0.163

[a] Average particle size is indicated as opening, in millimeters, of sieve retaining 50% of mixture. Initial average particle sizes in coarse, medium, and fine size ranges of each mixture, respectively, are in approximate ratio of $2:\sqrt{2}:1$.

proportions of the solid ingredients of the mixture in each particle-size fraction. The distribution patterns of superphosphate and ammonium sulfate were the same in all four distribution patterns of the mixture. Thus the difference in patterns of the mixtures is derived from changing the particle-size distribution of the potassium chloride present. When the major proportion (25/35 or 71%) of the potassium chloride was in the coarse size fraction, it produced the coarse-skewed pattern for mixture 2; when in the middle size fraction, it produced the normal pattern for mixture 3; and in the fine size fraction, fine-skewed pattern for mixture 4 in each particle-size range.

The design of the experiment thus gives mixtures representing systematic change, both in the initial particle size of all solid constituents (mixtures 1c to 1f, 2c to 2f, 3c to 3f, and 4c to 4f, respectively), and in the initial particle size of the potassium chloride (mixtures 1c to 4c, 1m to 4m, and 1f to 4f, respectively).

Table III shows the initial average particle size of each mixture in the three particle-size ranges studied. The average particle size, or the geometric mean particle size, is designated as the opening of the sieve retaining 50% by weight of the sample.

Granulation Procedure

Batches of 600 grams of mixture were individually prepared from the stock size fractions of each solid material. Each batch was wetted, mixed, placed in a preheated rotary drum, and ammoniated and granulated at 100° C. Subsequent batches of each mixture were similarly treated in the presence of increasing increments of water until the moisture content exceeded that required for maximal production of on-size (6–20 mesh) granules as evidenced by excessive production of oversize (+6 mesh) granules. Each batch was air-dried overnight and subjected to screen analysis.

An average of seven granulation trials on each of the 12 mixtures or a total of 84 batch-granulation trials were required to obtain the data presented in this paper. These trials were conducted without recycling undesirable size fractions of the product from the granulator. The results reveal the effect of particle size of the feed mixture on granulation efficiency and should be equally applicable to continuous operation with recycle.

Granulation Efficiency

It has been common practice in fertilizer technology to measure granulation efficiency on the basis of product yield alone. However, the manufacturer of mixed fertilizers is interested not only in product yield but also in the behavior of the mixture during processing and the quality of the granular product. Product yield may vary over a wide range when agglomeration of a given mixture is sensitive to slight changes in moisture content of the mixture during processing. The laboratory investigation herein described included measurement of the variation in yield of on-size product (6–20 mesh) when the moisture content of the mixture during processing was varied within the range of 90 to 100% of the optimum moisture requirement for agglomeration.

Another important criterion of granulation efficiency is the uniformity of nutrient distribution in the granular product. Nutrient uniformity in the products of the 12 mixtures used in this study was determined from the results of determinations of N, P, and K in the size fractions of the entire product from the granulator. The relative growth in volume of the particle during processing indicates the degree of agglomeration that has occurred. The relative increase in volume of the particle during granulation of the 12 mixtures was measured on the basis of increase in average particle size of the mixture during processing. This measurement is a potentially useful tool in explaining or predicting nutrient uniformity in the granular product.

Thus, the criteria used in evaluating granulation efficiency were behavior of the mixture during processing, product yield, and nutrient uniformity in the product.

Processing Behavior and Product Yields. Product yields, as affected by variation in moisture content of the 12 mixtures during processing, are given in Table IV. The average moisture requirement (column 2) for obtaining optimum yield of on-size product increased from 21.3% for mixtures 1c to 4c in the coarse range of particle size to 24.2% for mixtures 1f to 4f in the fine range. Results of screen analyses of the products from the granulator (columns 3 to 5) indicate a general decrease in the proportion of on-size product (column 4) with increasing degree of fineness of the initial mixture. The coarse-skewed distribution pattern of mixtures 2c and 2m in the coarse and medium ranges of particle size, respectively, gave the highest proportion of on-size product in their respective size ranges.

Decreasing the proportion of water used in processing to give moisture contents over the range of 90 to 100% of the optimum moisture requirement for agglomeration (columns 7 and 8, Table

Table IV. Effect of Moisture Variation on Product Yields

Mixture No.	Optimum Moisture Requirement, %	Size Analysis of Product from Granulator[a]				Variation in Moisture Content below Optimum Moisture Requirement, %		Variation in Yield of On-Size Product,[c] %	
		Oversize (+6 mesh), %	On-size (6–20 mesh), %	Fines (−20 mesh), %	Weighted average particle size, mm.	Range[b]	Variation	Range	Variation
1c	22.1	15	67	18	1.499	19.9–22.1	2.2	45–62	17
2c	20.3	12	70	18	1.372	18.3–20.3	2.0	55–64	9
3c	21.3	12	66	22	1.321	19.3–21.3	2.0	41–61	20
4c	21.3	14	62	24	1.346	19.2–21.3	2.1	41–57	16
Av.	21.3	13	67	20	1.385	19.2–21.3	2.1	46–61	15
1m	22.6	11	58	32	1.473	20.4–22.6	2.2	32–58	26
2m	22.6	17	64	19	1.651	20.3–22.6	2.3	36–64	28
3m	22.8	17	52	31	1.448	20.6–22.8	2.2	34–52	18
4m	23.2	17	57	26	1.499	21.1–23.3	2.2	38–57	19
Av.	22.8	15	58	27	1.518	20.6–22.8	2.2	35–58	23
1f	24.0	10	60	30	1.346	21.8–24.0	2.2	28–60	32
2f	23.8	13	55	32	1.372	21.6–23.8	2.2	30–55	25
3f	24.3	21	50	29	1.778	22.0–24.3	2.3	26–50	24
4f	24.5	14	54	32	1.524	22.1–24.5	2.4	33–54	21
Av.	24.2	14	55	31	1.505	21.9–24.2	2.3	29–55	26

[a] Averages of three granulation trials which yielded highest proportion of on-size product. [b] Moisture contents range from about 90 to 100% of optimum moisture content. [c] Difference in proportion of on-size material before and after granulation divided by proportion finer than 20 mesh initially. Thus, on-size material present initially (12 to 16%) in mixtures 1c–4c was not considered as yield of on-size product.

Table V. Nutrient Analyses of Composite Products from Granulator

Mixture No.	Proportion in Size Fraction, % (Dry Basis)			N, P, and K in Size Fractions[a] of Composite Product, % (Dry Basis)											
				N				P				K			
	+6	6–20	−20	+6	6–20	−20	Mean[b]	+6	6–20	−20	Mean[b]	+6	6–20	−20	Mean[b]
1c	10.4	60.1	29.5	3.78	4.90	4.48	4.66	8.97	9.30	8.96	9.17	17.77	15.94	18.86	16.99
2c	7.8	65.1	27.1	4.48	4.96	4.31	4.75	9.15	9.31	8.63	9.12	16.23	15.15	19.47	16.40
3c	8.4	59.4	32.2	4.22	4.92	4.44	4.71	8.79	9.34	8.82	9.13	18.08	15.33	19.31	16.84
4c	8.3	56.7	35.0	3.99	4.78	4.70	4.69	8.54	8.98	9.40	9.09	18.93	16.49	17.22	16.94
1m	6.3	42.3	51.4	4.38	4.98	4.65	4.77	8.95	9.08	9.22	9.14	17.39	16.31	17.90	17.19
2m	10.5	48.4	41.1	4.39	5.10	4.38	4.73	9.07	9.23	8.96	9.10	16.29	15.34	18.74	16.83
3m	9.2	42.4	48.4	3.89	4.89	4.65	4.68	8.67	8.92	9.49	9.18	17.95	16.44	17.23	16.96
4m	8.1	45.5	46.4	3.90	4.75	4.66	4.64	8.66	8.58	9.72	9.12	18.20	17.47	16.23	16.95
1f	5.0	35.9	59.1	4.29	4.92	4.69	4.75	8.89	8.65	9.28	9.04	17.43	16.59	17.64	17.26
2f	6.3	41.2	52.5	4.38	5.07	4.58	4.77	8.96	8.99	9.13	9.06	16.41	15.12	18.35	16.90
3f	10.0	39.6	50.4	4.27	4.85	4.73	4.73	8.80	8.61	9.57	9.11	17.72	16.83	17.13	17.07
4f	8.3	44.5	47.2	4.30	4.67	4.62	4.62	8.95	8.47	9.68	9.08	17.26	17.22	16.26	16.77

[a] Averages of duplicate nutrient analyses. [b] Weighted average analyses of all size fractions.

Table VI. Particle Growth and Nutrient Uniformity in Composite Products from Granulator

Mixture No.	Av. Particle Size before and after Granulation, Mm.		Relative Volume Growth of Particle, $(df^3 - di^3)/di^3$	Equivalent Av. % Deviation[a]			
	Before (di)	After (df)		N	P	K	Sum of N, P, K
1c	0.417	1.168	21	11.5	2.0	7.8	8.1
2c	0.518	1.092	8	6.8	3.4	11.7	8.0
3c	0.417	1.080	16	7.3	3.2	10.7	7.8
4c	0.325	1.067	34	8.6	4.0	7.0	6.8
Av.			20	8.6	3.2	9.3	7.7
1m	0.295	0.762	16	5.6	1.4	3.9	4.0
2m	0.365	0.991	19	7.5	1.2	8.5	6.6
3m	0.295	0.914	29	10.1	4.1	3.9	6.7
4m	0.231	0.914	61	9.3	5.9	5.2	7.0
Av.			41	8.1	3.2	5.4	6.1
1f	0.208	0.635	27	6.0	3.0	2.6	4.2
2f	0.259	0.813	30	6.3	0.9	8.0	5.9
3f	0.208	0.833	63	5.8	4.7	2.4	4.5
4f	0.163	0.914	175	4.0	5.5	2.9	4.3
Av.			74	5.5	4.7	4.0	4.7

[a] Equivalent average percentage deviation from weighted average analysis, *EAPD*, is square root of quantity obtained by dividing sum of percentage deviations squared by number of observations; $EAPD = \sqrt{\Sigma PD^2/n}$. Three observations for each nutrient corresponded to three size fractions analyzed, +6, 6–20, and −20 mesh, respectively. Values in last column represent nine nutrient observations.

IV) caused considerable variation in yield of on-size product, as indicated in the last two columns of the table. These results confirm the findings of previous investigators (*6*, *8–10*) in that the use of some coarse material in the initial mixture decreases the moisture requirement for agglomeration, increases the yield of on-size product, and tends to decrease the variation in product yield that frequently occurs as a result of slight variation in water addition during continuous processing.

Granule Formation. Determination of the moisture requirement for optimum yield of on-size product required about seven batch granulation trials with addition of increasing increments of water on each of the 12 mixtures, or a total of 84 granulation trials. The composite results of particle-size analyses of each of the dried batches from the granulator in these trials provide excellent data for illustrating the general trend of granule formation in the mixture

Table VII. Effect of Particle Growth on Nutrient Uniformity in On-Size Portion of Product from Granulator

Mixture No.	Relative Growth of Particle $(df^3 - di^3)/di^3$ for Final Av. Particle Size[a] of			% Deviation in N, P, and K Contents of On-Size Portion of Product for Final Av. Particle Sizes[a] of 20, 14, and 10 Mesh, Respectively												
				N			P			K			Sum of N, P, and K, EAPD[b]			
	20	14	10	20	14	10	20	14	10	20	14	10	20	14	10	Mean
1c	7	21	61	+ 7.5	+5.8	+6.8	+0.2	−0.2	−0.5	− 8.4	−5.2	−2.8	6.5	4.5	4.3	5.1
2c	3	10	31	+ 5.8	+5.8	+3.6	+1.6	+1.4	+0.6	− 9.5	−5.9	−3.3	6.5	4.8	2.8	5.0
3c	7	21	61	+ 8.0	+4.4	+1.0	+2.8	+1.2	+0.5	−12.9	−6.2	−2.5	8.9	4.4	1.6	5.8
4c	16	45	130	+ 2.4	+2.8	+3.8	−1.5	−0.8	+0.2	− 3.0	+0.4	−0.8	2.4	1.7	2.2	2.1
1m	22	61	174	+ 6.4	+3.8	+1.8	−1.8	−2.0	−2.5	− 3.6	−0.2	−1.7	4.4	2.5	2.0	3.1
2m	11	32	92	+11.1	+5.8	+1.9	+0.8	+0.2	−0.6	− 9.4	−4.8	−2.2	8.4	4.1	1.7	5.6
3m	22	61	174	+ 5.8	+3.5	+3.7	−3.2	−2.4	−2.0	− 4.6	−0.3	+1.0	4.7	2.5	2.5	3.4
4m	46	128	364	+ 2.9	+4.2	+2.3	−6.6	−3.8	−2.4	+ 4.1	+4.8	+4.9	4.8	4.3	3.4	4.2
1f	63	176	499	+ 6.0	+4.0	+0.4	−6.1	−4.0	−0.8	− 3.6	−1.6	−0.8	5.4	3.4	0.7	3.7
2f	32	91	258	+ 9.0	+5.4	+1.0	−1.2	−0.8	−0.8	−10.4	−6.0	−2.2	7.9	4.7	1.5	5.4
3f	63	176	499	+ 3.6	+3.6	+3.4	−7.8	−6.2	−4.0	+ 0.5	+2.0	+3.2	5.0	3.9	3.6	4.3
4f	132	367	1038	+ 1.4	+1.8	+3.7	−8.4	−7.2	−5.8	+ 5.8	+6.0	+6.1	6.0	5.5	5.3	5.6

[a] Final average particle size designated as mesh size of screen retaining 50% by weight of entire batch emerging from granulator. Values for per cent deviation corresponding to 20, 14, and 10 mesh taken from average particle-size curves illustrated in Figure 2. [b] *EAPD*, equivalent average percentage deviation, is square root of sum of percentage deviations squared divided by number of observations. $EAPD = \sqrt{\Sigma PD^2/n}$. Values in columns 14 through 16 represent three observations and last column represents nine observations.

during processing. Accordingly, Figure 1 illustrates the general relationship between average particle size and the distribution of size fractions in the processed material discharged from the granulator. The percentages of oversize, on-size, and fines were each plotted as a function of the average particle size for each of the 84 batches involved. At an average particle size of 0.833 mm. (20 mesh), the granular batch is about half on-size and half fines. Figure 1 shows that maximum yield of on-size product occurs when the average particle size of the granular batch is about 1.4 mm. (12 mesh). Increase in average particle size from 14 to 10 mesh is accompanied by rapid increase in oversize granules, a small decrease in on-size product, about 2%, and a considerable decrease in fines, 10%. Hence, granular products having an average particle size smaller than 20 mesh contain excessive proportions of fines (more than 50%) and those having an average particle size larger than 10 mesh contain excessive proportions of oversize (more than 19%). This range of average particle size of the mixture during processing represents the most critical stage of granule formation. Rapid drying and screening of samples to determine the average particle size at this stage of the process provide excellent data for process control in continuous operation.

Nutrient Analyses

Representative samples of the oversize (+6 mesh), on-size (6–20 mesh), and fines (−20 mesh) of each mixture were analyzed for total N, available P, and soluble K. The weighted mean nutrient analysis of the entire batch from the granulator was determined from the analytical data (Table V). The nitrogen means averaged 4.71%, the phosphorus means averaged 9.11%, and the potassium means averaged 16.93%. The wide range of analytical results for potassium was due in part to variation in potassium content of different particle-size fractions of the initial potassium chloride used. For example, the potassium content of the 14- to 20-mesh fraction of potassium chloride was only 48.6%, as compared with 50.7% for the 28- to 100-mesh fraction, and 50.1% for the 100- to 200-mesh fraction. This partially accounts for the low mean value for potassium content of mixture 2c. The nitrogen content of the oversize fraction (+6 mesh) was less than the mean for all size fractions, and that of the on-size fraction exceeded the mean for all size fractions in each of the granulated mixtures (Table V). The low nitrogen contents in the oversize fractions probably reflect the tendency of the wetted superphosphate to agglomerate rapidly, thus causing a decrease in surface area available for reaction with ammonia.

Superphosphate in the mixture tended to agglomerate more readily when the potassium chloride component was coarsest. For example, the phosphorus remaining in the fines (−20-mesh fraction) of mixtures 2c, 2m, and 2f averages only 8.91% [(8.63 + 8.96 + 9.13)/3], as compared with mixtures 4c, 4m, and 4f, averaging 9.60% [(9.40 + 9.72 + 9.68)/3]. Conversely, potassium chloride tends to agglomerate more readily when the superphosphate is coarsest. For example, the potassium remaining in the fine fractions of mixtures 2c, 2m, and 2f averages 18.85%, as compared with mixtures 4c, 4m, and 4f, averaging only 16.57%.

Particle Growth and Nutrient Uniformity. Attention was given to the relationship between the degree of uniformity of nutrients in the composite products of each mixture from the granulator and the particle growth resulting from agglomeration. The relative volume growth of the particle was determined from the average particle size of the mixtures before and after granulation, as shown in Table VI (columns 2 to 4). The growth in volume of the particle is indicated by the formula $(df^3 - di^3)/di^3$, where di is the average initial diameter of the particle and df is the average final diameter. The degree of uniformity of nutrient distribution was ascertained as the equivalent average percentage deviation, *EAPD* (Table VI).

Particle growth, as indicated by the relative increase in volume of the particle during processing, tended to increase with increasing degree of fineness of the initial mixture. Attending the increase in growth of the particle was an increase in average uniformity of nutrients in the composite products from the granulator (column 8). Similar trends occurred in deviations of nitrogen (column 5) and of potassium (column 7).

Results of the effect of initial particle size on nutrient uniformity in products of individual mixtures within a given initial particle-size range (columns 5 to 8) are not conclusive. However, there is a general tendency for improvement of potassium uniformity and impairment of phosphorus uniformity with decrease in the initial particle size of all ingredients of the mixture or of the potassium chloride alone. The magnitude of the nutrient deviations (*EAPD*) for corresponding mixtures having the same initial particle-size distribution patterns in the coarse, medium, and fine ranges of particle size varied widely. These results indicate that the initial particle size, not only of potassium chloride but of all the ingredients of the mixture, is important to the uniformity of nutrient distribution. However, mixtures 2c,

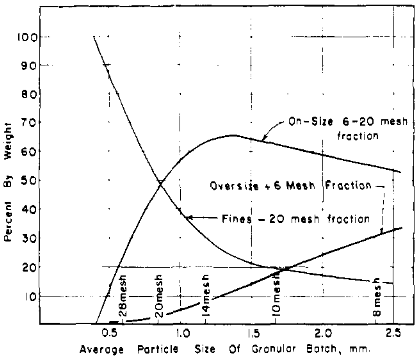

Figure 1. Change in distribution of size fractions with growth of particle during granulation of mixed fertilizers

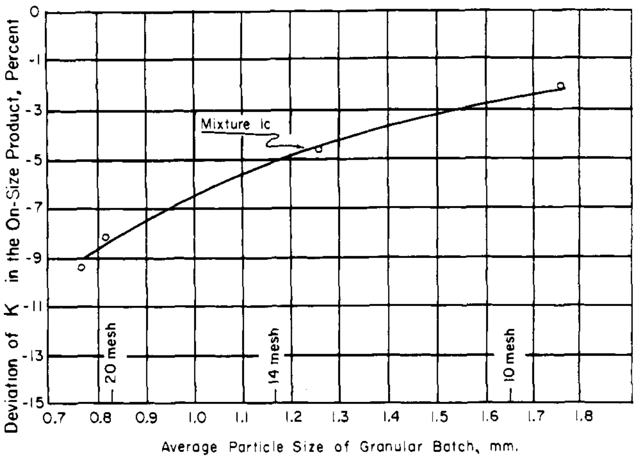

Figure 2. Deviation in potassium content of on-size product with growth of particle during granulation of mixed fertilizers

2m, and 2f, representing coarse-skewed distribution patterns with 71% of the potassium chloride in the coarse particle-size fraction, exhibited the least degree of potassium unformity in their respective particle-size ranges.

Nutrient Distribution in On-Size Product. In addition to the investigation of nutrient distribution in the composite product from the granulator, a further study was made of nutrient distribution in the on-size (6–20 mesh) product at different stages of granule growth during processing. Four individual granulated batches from each of the 12 mixtures were selected on the basis of consecutive increase in average particle size from about 0.7 mm. (24 mesh) to 1.8 mm. (approximately 9 mesh). The on-size fraction of each batch was analyzed for N, available P, and K.

The percentage deviation from the mean analyses of nutrients in the corresponding granular batch was then calculated for each nutrient in the on-size fraction of the batch and plotted as a function of the average particle size of the granular batch from which the on-size fraction was taken. Figure 2 illustrates the value of the data for observing change in distribution of potassium in the on-size product of mixture 1c during growth of the particle in the granulation process. Deviation in nutrient content of the on-size product corresponding to granular batches having average particle sizes of 20, 14, and 10 mesh may be obtained by interpolation. Thus, potassium uniformity in the on-size product of mixture 1c improves with increase in average particle size of the granular batch from 20 to 10 mesh. This range of average particle size (Figure 2) corresponds to that shown in Figure 1 as the most critical for granule formation during processing. Similar data obtained for each nutrient in on-size fractions from each of the 12 mixtures are given in Table VII, which shows the influence of particle growth during processing on nutrient uniformity in the on-size product. The relative particle growth when the average particle size of the granular batch was 20, 14, and 10 mesh, respectively, is given in columns 2 to 4; the corresponding individual nutrient deviations. in columns 5 to 13; and the equivalent average percentage deviation (*EAPD*) of the sum of the three nutrients, in the last four columns.

Deviation of nitrogen in all of the on-size products (columns 5 to 7) was above the mean nitrogen content of the composite size fractions in the batch from the granulator; those of phosphorus and potassium were frequently below the mean (columns 8 to 13). Increase in particle growth as evidenced by increase in average particle size of the granular batch from 20 to 10 mesh during processing (columns 2 to 4) was accompanied by a general decrease in the over-all percentage deviation of the three nutrients in the on-size product (columns 14 to 16). Thus, the uniformity of nutrient distribution was improved and better apherence of nutrient content to the grade of the fertilizer was obtained by granule buildup to the larger particle size, regardless of the initial particle-size pattern or range of particle size of the initial mixture.

The data in Table VII also indicate the particle-size effect of potassium chloride on nutrient distribution in the on-size product. Mixtures such as 4m and 4f, initially containing high proportions of potassium chloride finer than 100-mesh, tended to give on-size products in which the potassium contents were well above the mean content of potassium in the entire mixture and those containing lesser proportions of fine potassium chloride, such as mixtures 2m and 2f, tended to give on-size products having potassium contents well below the mean.

Of mixtures 1c to 4c, having an initial particle-size range of 14 to 100 mesh, fine-skewed mixture 4c initially containing 71% of its potassium chloride in the 48- to 100-mesh fraction, yielded on-size granular products having the best nutrient uniformity (last column). On-size products obtained with varying proportions of potassium chloride finer than 100 mesh tended to have better over-all nutrient uniformity (last column) when the potassium chloride of the initial mixture was equally distributed among all size fractions (mixtures 1m and 1f) or was present largely in the middle size fraction (mixtures 3m and 3f).

Discussion

Decrease in particle size of raw materials entering the granulation process favors granule growth and nutrient uniformity in the product but reduces processing efficiency and product yields. These opposing effects indicate that a compromise in particle size of raw materials is a wise choice in plant operation. Raw materials, largely in the particle-size range of 14 to 100 mesh, are particularly suited to the granulation of low-nitrogen fertilizers in rotary equipment. In such mixtures, the use of 48- to 100-mesh potassium chloride instead of coarser material greatly enhances nutrient distribution in the final product. Nutrient uniformity is also greatly improved by operating the process so as to obtain an average particle size of approximately 10 mesh in the granular product.

The batch tests used in this study differed from normal continuous operation in that the oversize and undersize material was not recycled. However, the results indicate that the particle sizes of all solid materials entering the granulation process are important to granulation efficiency. Aside from the other properties of recycle material, such as moisture content and temperature which influence the behavior of the process, the particle size of the recycle will exhibit the same influence on processing behavior, product yield, and nutrient uniformity as any other component of the feed mixture. Decrease in particle size of recycle material favors granule growth and nutrient uniformity in the final product but at the same time reduces processing efficiency and product yields.

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NUTRIENT AVAILABILITY IN SOIL

Availability of Minerals from Magnesium Ammonium Phosphates

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Soil conditions affecting the availability of minerals from $MgNH_4PO_4 \cdot H_2O$ have been investigated, and the successful use of this fertilizer as a source of N to produce potted flowering crops from a single preplant application has been demonstrated. Saturation of $MgNH_4PO_4 \cdot H_2O$ occurs at about 1.7 meq. per liter at 23.5° C. Solubility is only moderately affected in the temperature range from 10° to 40° C. Dissolution is enhanced by acid soil conditions, increased levels of soil moisture, and nitrification. Surface applications result in a slower release of nitrogen than soil incorporations of fertilizer. Particle size of the fertilizer exerts a strong influence on the rate of dissolution at concentrations far from saturation, but the rate of dissolution is also strongly influenced by the saturation deficiency which minimizes the effect of particle size. When incorporated in the soil, the effect of particle size of $MgNH_4PO_4 \cdot H_2O$ on plant growth was smaller than would be anticipated from surface area considerations.

METAL ammonium phosphates have recently been proposed as long-lasting, nonburning fertilizer sources of N, P, and various metals including Mg, Fe^{+2}, Zn, Mn^{+2}, Cu, and Co (*1*). The general formula for this group of compounds is $MeNH_4PO_4 \cdot xH_2O$. With the exception of the Zn compound, which is stable under ordinary conditions in the anhydrous state, all compounds are conveniently stable as the monohydrate. Since they are compounds of limited solubility, their utility as fertilizers is particularly attractive in those applications where leaching losses of soluble fertilizers would be high or where low "burn-hazard" or long duration is important. In this respect, this group of fertilizers is of particular interest for the production of container nursery stock, flower crops, landscape installations, and turfgrass (*5*).

This paper reports on several studies of various conditions which may be expected to affect the availability of minerals from metal ammonium phosphates.

Methods and Materials

The fertilizer materials used in these studies were commercial products and were classified in various particle size groups as summarized in Table I.

Solubility. A series of experiments were conducted to determine the presence of soluble impurities, solubility at saturation, influence of particle size and temperature on the rate of solution and solubility, and influence of the presence or removal of the products of solution on the dissolution of the minerals. In general, the procedure followed was to add a quantity of the material under investigation to a flask containing distilled water and agitate by aeration in a constant temperature room. Samples of the supernatant were taken periodically for conductometric analysis or for analysis of Mg, P, or NH_4. Additional pertinent details related to these experiments are given in the discussion or in the figure legends.

Nitrification. The influence of nitrification on the amount of dissolution of $MgNH_4PO_4 \cdot H_2O$ was investigated using